

LOAN DOCUMENT

DTIC ACCESSION NUMBER	PHOTOGRAPH THIS SHEET	INVENTORY
	LEVEL	①
	Work Plan for a Demonstration of ... DOCUMENT IDENTIFICATION mar 97	
DISTRIBUTION STATEMENT A Approved for Public Release Distribution Unlimited		
DISTRIBUTION STATEMENT		
DATE RECEIVED IN DTIC		
REGISTERED OR CERTIFIED NUMBER		
PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-FDAC		

ACCESSION FOR

NTIS	ORIGIN	<input checked="" type="checkbox"/>
DTIC	TRAC	<input type="checkbox"/>
UNANNOUNCED		<input type="checkbox"/>
JUSTIFICATION		

BY

DISTRIBUTION/

AVAILABILITY CODES

DISTRIBUTION	AVAILABILITY AND/OR SPECIAL
A-1	

DATE RECEIVED IN DTIC

20010116 020

DATE RETURNED

DATE RECEIVED IN DTIC

REGISTERED OR CERTIFIED NUMBER

H
A
N
D
L
E

W
I
T
H

C
A
R
E

Work Plan for a Demonstration of Remediation by Natural Attenuation for Groundwater at Sites FTA 2 and Area A



**Tinker Air Force Base
Oklahoma City, Oklahoma**

Prepared For

**Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base
San Antonio, Texas**

and

**Tinker Air Force Base
Oklahoma City, Oklahoma**

March 1997



**PARSONS
ENGINEERING SCIENCE, INC.**

1700 Broadway, Suite 900 • Denver, Colorado 80290

AQM01-04-0627

DEFENSE TECHNICAL INFORMATION CENTER REQUEST FOR SCIENTIFIC AND TECHNICAL REPORTS

Title AFCEE Collection

1. Report Availability (Please check one box)

- ☒ This report is available. Complete sections 2a - 2f.
☐ This report is not available. Complete section 3.

**2a. Number of
Copies Forwarded**

1 each

2b. Forwarding Date

July/2000

2c. Distribution Statement (Please check ONE box)

DoD Directive 5230.24, "Distribution Statements on Technical Documents," 18 Mar 87, contains seven distribution statements, as described briefly below. Technical documents **MUST** be assigned a distribution statement.

- ☒ **DISTRIBUTION STATEMENT A:** Approved for public release. Distribution is unlimited.
- ☐ **DISTRIBUTION STATEMENT B:** Distribution authorized to U.S. Government Agencies only.
- ☐ **DISTRIBUTION STATEMENT C:** Distribution authorized to U.S. Government Agencies and their contractors.
- ☐ **DISTRIBUTION STATEMENT D:** Distribution authorized to U.S. Department of Defense (DoD) and U.S. DoD contractors only.
- ☐ **DISTRIBUTION STATEMENT E:** Distribution authorized to U.S. Department of Defense (DoD) components only.
- ☐ **DISTRIBUTION STATEMENT F:** Further dissemination only as directed by the controlling DoD office indicated below or by higher authority.
- ☐ **DISTRIBUTION STATEMENT X:** Distribution authorized to U.S. Government agencies and private individuals or enterprises eligible to obtain export-controlled technical data in accordance with DoD Directive 5230.25, Withholding of Unclassified Technical Data from Public Disclosure, 6 Nov 84.

2d. Reason For the Above Distribution Statement (in accordance with DoD Directive 5230.24)

2e. Controlling Office

HQ AFCEE

**2f. Date of Distribution Statement
Determination**

15 Nov 2000

3. This report is NOT forwarded for the following reasons. (Please check appropriate box)

- ☐ It was previously forwarded to DTIC on _____ (date) and the AD number is _____
- ☐ It will be published at a later date. Enter approximate date if known. _____
- ☐ In accordance with the provisions of DoD Directive 3200.12, the requested document is not supplied because:

Print or Type Name

Laura Peña

Telephone

210-536-1431

Signature

Laura Peña

(Print and Initial)

AD Number M01-04-0627

**WORK PLAN FOR A TREATABILITY STUDY
IN SUPPORT OF REMEDIATION BY NATURAL ATTENUATION
AT SITES FTA 2 AND AREA A**

at

**TINKER AIR FORCE BASE
OKLAHOMA CITY, OKLAHOMA**

February 1997

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE

TECHNOLOGY TRANSFER DIVISION

BROOKS AIR FORCE BASE

SAN ANTONIO, TEXAS

AND

**TINKER AIR FORCE BASE
OKLAHOMA CITY, OKLAHOMA**

Prepared by:

Parsons Engineering Science, Inc.

1700 Broadway, Suite 900

Denver, Colorado 80290

TABLE OF CONTENTS

	Page
ACRONYMS AND ABBREVIATIONS	vi
SECTION 1 - INTRODUCTION	1-1
1.1 Scope of Current Work Plan.....	1-3
1.2 Background.....	1-6
1.2.1 FTA 2 Background	1-8
1.2.2 Area A Background	1-10
SECTION 2 - DATA REVIEW AND CONCEPTUAL MODEL DEVELOPMENT	2-1
2.1 Data Review.....	2-1
2.1.1 Topography, Surface Hydrology, and Climate.....	2-2
2.1.2 Overview of Geology and Hydrogeology	2-5
2.1.2.1 Regional Geology	2-5
2.1.2.2 Regional Hydrogeology	2-10
2.1.2.3 FTA 2 Geology and Hydrogeology.....	2-15
2.1.2.4 Area A Geology and Hydrogeology	2-19
2.1.3 Summary of Analytical Results for FTA 2	2-27
2.1.3.1 Soil Quality	2-27
2.1.3.2 Groundwater Quality.....	2-27
2.1.4 Summary of Analytical Results for Site Area A	2-32
2.1.4.1 Soil Quality	2-32
2.1.4.2 Groundwater Quality.....	2-34
2.2 Development of Conceptual Models.....	2-38
2.2.1 RNA and Groundwater Flow and Solute Transport Models.....	2-39
2.2.2 Biodegradation of Dissolved BTEX Contamination	2-41
2.2.3 Biodegradation of CAHs.....	2-45
2.2.3.1 Electron Acceptor Reactions (Reductive Dechlorination)	2-46
2.2.3.2 Electron Donor Reactions	2-48
2.2.3.3 Cometabolism.....	2-49
2.2.3.4 Behavior of Chlorinated Solvent Plumes.....	2-51
2.2.4 Initial Conceptual Model	2-53
2.2.4.1 Initial Conceptual Model for FTA 2.....	2-53
2.2.4.2 Initial Conceptual Model for Area A	2-54
2.2.5 Potential Pathways and Receptors.....	2-56
2.2.5.1 Potential Pathways and Receptors at FTA 2	2-56
2.2.5.2 Potential Pathways and Receptors at Area A.....	2-56

TABLE OF CONTENTS (CONTINUED)

	Page
SECTION 3 - COLLECTION OF ADDITIONAL DATA	3-1
3.1 Site Management	3-4
3.1.1 Base Support	3-4
3.1.2 Contingency Plans	3-6
3.1.2.1 Access and Coordination Contingencies	3-6
3.1.2.2 Equipment Contingencies	3-7
3.1.2.3 Sampling Location Contingencies	3-7
3.1.2.4 Abnormal Site Condition Contingencies	3-8
3.1.2.5 Drilling Permit Delays	3-8
3.1.2.6 Site Health and Safety Plan	3-9
3.1.3 Site Restoration and Waste Handling	3-9
3.2 Monitoring Point/Well Drilling, Soil Sampling, and Installation	3-10
3.2.1 Monitoring Point and Well Locations and Completion Intervals	3-11
3.2.1.1 FTA 2 Monitoring Point and Well Locations and Completion Intervals	3-11
3.2.1.2 Area A Monitoring Well Locations and Completion Intervals	3-13
3.2.2 Monitoring Point and Well Advancement and Installation Procedures	3-17
3.2.2.1 USZ Monitoring Points/Wells	3-19
3.2.2.2 LSZ Monitoring Wells	3-20
3.2.3 Collection of Soil Samples for Field Screening and Laboratory Analysis During Monitoring Well/Point Drilling	3-23
3.2.4 Equipment Decontamination During Drilling and Soil Sampling Activities	3-24
3.2.5 Monitoring Point Development and Records	3-24
3.2.6 Datum Survey	3-27
3.3 Groundwater Sampling Procedures	3-27
3.3.1 Groundwater Sampling Strategy	3-28
3.3.2 Preparation for Sampling	3-28
3.3.2.1 Equipment Cleaning	3-28
3.3.2.2 Equipment Calibration	3-29
3.3.3 Well and Monitoring Point Sampling Procedures	3-29
3.3.3.1 Preparation of Location	3-32
3.3.3.2 Water Level and Total Depth Measurements	3-32
3.3.3.3 Purging Before Sampling	3-33
3.3.3.4 Sample Extraction	3-33

TABLE OF CONTENTS (CONTINUED)

	Page
3.3.4 Onsite Groundwater Parameter Measurement	3-34
3.3.4.1 Dissolved Oxygen Measurements	3-34
3.3.4.2 pH, Temperature, and Specific Conductance	3-35
3.3.4.3 Carbon Dioxide Measurements	3-35
3.3.4.4 Alkalinity Measurements	3-35
3.3.4.5 Nitrate- and Nitrite-Nitrogen Measurements	3-36
3.3.4.6 Sulfate and Sulfide Sulfur Measurements	3-36
3.3.4.7 Total Iron, Ferrous Iron, and Ferric Iron Measurements	3-36
3.3.4.8 Manganese Measurements	3-37
3.3.4.9 Oxidation/Reduction Potential	3-37
3.4 Mobile LNAPL Sampling	3-38
3.5 Handling of Samples for Laboratory Analysis	3-38
3.5.1 Sample Preservation	3-38
3.5.2 Sample Container and Labels	3-38
3.5.3 Sample Shipment	3-39
3.5.4 Chain-of-Custody Control	3-40
3.5.5 Sampling Records	3-40
3.5.6 Laboratory Analyses	3-41
3.6 Aquifer Testing	3-42
3.6.1 Definitions	3-42
3.6.2 Equipment	3-43
3.6.3 General Test Methods	3-44
3.6.4 Falling Head Test	3-44
3.6.5 Rising Head Test	3-47
3.6.6 Slug Test Data Analysis	3-47
SECTION 4 - QUALITY ASSURANCE/QUALITY CONTROL	4-1
SECTION 5 - DATA ANALYSIS AND REPORT	5-1
SECTION 6 - REFERENCES	6-1
Appendix A Analytical Methods, Data Use, And Packaging Requirements For Soil And Groundwater Samples	
Appendix B Additional Site Information - FTA 2	
Appendix C Additional Site Information - Area A	
Appendix D Tinker AFB Well Installation Standards	

TABLE OF CONTENTS (CONTINUED)

LIST OF TABLES

No.	Title	Page
2.1	Major Geologic Units in the Vicinity of Tinker AFB	2-6
2.2	Monitoring Well Summary and September 1996 Groundwater Elevations, FTA 2	2-17
2.3	Monitoring Well Summary and September 1996 Groundwater Elevations, Area A	2-24
2.4	Summary of Volatile Organic Compounds in FTA 2 Groundwater, July to September 1996	2-28
2.5	Summary of Volatile Organic Compounds in Area A Groundwater, August to September 1996	2-35
2.6	Coupled Oxidation Reactions for BTEX Compounds	2-43
3.1	Analytical Protocols for Groundwater, Free Product, and Soil Samples	3-2
3.2	Proposed Monitoring Well Summary, FTA 2	3-14
3.3	Proposed Monitoring Well Summary, Area A	3-16
4.1	QA/QC Sampling Program	4-2
5.1	Example Report Outline	5-4

FIGURES

No.	Title	Page
1.1	Location of Tinker Air Force Base	1-7
1.2	Location of Sites FTA 2 and Area A	1-9
1.3	Site Location Map, Fire Training Area 2	1-11
1.4	Site Location Map, Area A Service Station	1-14
2.1	Topographic Map of Fire Training Area 2	2-3
2.2	Topographic Map of Area A Service Station	2-4
2.3	Surface Geologic Map, Tinker Air Force Base	2-8
2.4	Location of Hydrogeologic Cross-Sections A-A' and B-B'	2-12
2.5	Hydrogeologic Cross-Section A-A'	2-13
2.6	Hydrogeologic Cross-Section B-B'	2-14
2.7	Hydrogeologic Cross-Section C-C', FTA 2	2-16
2.8	Upper Saturated Zone Potentiometric Surface, September 1996, FTA 2	2-18
2.9	Lower Saturated Zone Potentiometric Surface, September 1996, FTA 2	2-20
2.10	Hydrogeologic Cross-Section D-D', Area A Service Station	2-21

TABLE OF CONTENTS (CONTINUED)

FIGURES (Continued)

No.	Title	Page
2.11	Hydrogeologic Cross-Section E-E', Area A Service Station.....	2-22
2.12	Upper Saturated Zone Potentiometric Surface, September 1996, Area A Service Station	2-25
2.13	Lower Saturated Zone Potentiometric Surface, September 1996, Area A Service Station	2-26
2.14	Chlorinated Aliphatic Hydrocarbons Detected in USZ Groundwater, July to September 1996, FTA 2	2-29
2.15	TCE Concentrations in USZ, Fire Training Area 2, July to September 1996	2-31
2.16	Total BTEX Concentrations in Soil at Approximately 10 feet bgs, Area A Service Station	2-33
2.17	Total BTEX Concentrations in Upper Saturated Zone, Area A Service Station.....	2-36
2.18	Chlorinated Aliphatic Hydrocarbons Detected in Groundwater, August to September 1996, Area A Service Station.....	2-37
2.19	Anaerobic Reductive Dehalogenation	2-47
2.20	Aerobic Biodegradation Pathways	2-50
3.1	Proposed Sampling Locations, Fire Training Area 2	3-12
3.2	Proposed Sampling Locations, Area A Service Station.....	3-15
3.3	Geologic Boring Log.....	3-18
3.4	Single-Cased Monitoring Point Construction Diagram	3-21
3.5	Double-Cased Monitoring Well Construction Diagram.....	3-22
3.6	Monitoring Well Development Record.....	3-26
3.7	Groundwater Sampling Record.....	3-30
3.8	Aquifer Slug Test Data Form.....	3-46

ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
AOC	Area of Concern
Area A	Area of Concern "A" (Base Service Station)
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylene
°C	degrees Celsius
CAH	chlorinated aliphatic hydrocarbon
CFR	Code of Federal Regulations
CO ₂	carbon dioxide
DCA	dichloroethane
DCE	dichloroethene
DO	dissolved oxygen
DOD	Department of Defense
ERI	Environmental Recovery, Inc.
ft/ft	feet per foot
FTA 2	Fire Training Area 2
GWTP	groundwater treatment plant
HDPE	high density polyethylene
HSA	hollow-stem auger
HWBZ	Hennessey water-bearing zone
ID	inside diameter
IT	IT Corporation
IRP	Installation Restoration Program
IWTP	industrial wastewater treatment plant
K	hydraulic conductivity
LCS	laboratory control sample

LMB	laboratory method blank
LNAPL	light non-aqueous phase liquid
LSZ	lower saturated zone
LTM	long-term monitoring
$\mu\text{g/kg}$	micrograms per kilogram
$\mu\text{g/L}$	micrograms per liter
mg/L	milligrams per liter
MSDS	material data safety sheets
msl	mean sea level
NGVD	National Geodetic Vertical Datum
NRMRL	National Risk Management Research Laboratory
OAC	Oklahoma Administrative Code
OD	outside diameter
ORD	USEPA Office of Research and Development
ORP	oxidation reduction potential
OSWER	USEPA Office of Solid Waste and Emergency Response
OVM	organic vapor meter
PA	preliminary assessment
PAH	polynuclear aromatic hydrocarbon
Parsons ES	Parsons Engineering Science, Inc.
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
POC	point of contact
ppmv	parts per million, volume by volume
PVC	polyvinyl chloride
QA	quality assurance
QC	quality control
RAP	remedial action plan
RCRA	Resource Conservation and Recovery Act
redox	reduction/oxidation

RFI	RCRA Facility Investigation
RNA	remediation by natural attenuation
SI	site inspection
SVOC	semivolatile organic compound
SWMU	solid waste management unit
T	transmissivity
TCA	trichloroethane
TCE	trichloroethene
TCLP	toxicity characteristics leaching procedure
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TS	Treatability Study
TT	Tetra Tech, Inc.
USACE	United States Army Corps of Engineer
USEPA	US Environmental Protection Agency
UST	Underground Storage Tank
USZ	upper saturated zone
VC	vinyl chloride
VOC	volatile organic compound
WSCI	Water and Soil Consultants, Inc.

SECTION 1

INTRODUCTION

This work plan, prepared by Parsons Engineering Science, Inc. (Parsons ES), presents the scope of work required for the collection of data necessary to conduct a treatability study (TS) for groundwater contaminated with chlorinated aliphatic hydrocarbons (CAHs) and benzene, toluene, ethylbenzene, and xylenes (BTEX) at two sites located at Tinker Air Force Base (AFB), in Oklahoma City, Oklahoma (the Base). The two sites to be investigated are Fire Training Area 2 (FTA 2), and the former Base service station (Area A). Hydrogeologic and groundwater chemical data collected under this program can also be used to evaluate various engineered remedial options; however, this work plan is oriented toward the collection of hydrogeologic data to be used in support of remediation by natural attenuation (RNA) with long-term monitoring (LTM) for restoration of groundwater contaminated with CAHs and BTEX.

As used in this report, RNA refers to a management strategy that relies on natural attenuation mechanisms to remediate contaminants dissolved in groundwater and to control receptor exposure risks associated with contaminants in the subsurface. The United States Environmental Protection Agency (USEPA) Offices of Research and Development (ORD) and Solid Waste and Emergency Response (OSWER) have proposed the following definition of natural attenuation (Wilson, 1996):

The biodegradation, dispersion, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the ecosystem.

As suggested by this definition, mechanisms for natural attenuation of CAHs and BTEX include advection, dispersion, dilution from recharge, sorption, volatilization, and biodegradation. Of these processes, biodegradation is the primary mechanism working to transform contaminants into innocuous byproducts. Contaminant destruction occurs through natural attenuation when indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without the addition of nutrients. Patterns and rates of natural attenuation can vary markedly from site to site depending on governing physical and chemical processes.

RNA is advantageous for the following reasons:

- Contaminants can ultimately be transformed to innocuous byproducts (e.g., carbon dioxide, ethene, or water), not just transferred to another phase or location within the environment;
- Current pump-and-treat technologies are energy intensive and generally not effective in reducing residual contamination;
- The process is nonintrusive and allows continuing use of infrastructure during remediation;
- Current engineered remedial technologies may pose a greater risk to potential receptors than RNA (e.g., contaminants may be transferred into another medium during remediation activities); and
- RNA is less costly than conventional, engineered remedial technologies.

The disadvantages of RNA include the following:

- Contaminants considered to be more mobile and toxic can be produced as byproducts of biodegradation [e.g., vinyl chloride (VC)];

- The effectiveness of RNA is generally limited by site geochemistry and the availability of substrates; and
- RNA frequently takes longer to reach specified concentration limits than other remedial alternatives.

This work plan was developed on the basis of discussions among representatives from Tinker AFB, the Air Force Center for Environmental Excellence (AFCEE), the USEPA National Risk Management Research Laboratory (NRMRL), and Parsons ES. These discussions included a roundtable meeting attended by representatives of these four organizations at Tinker AFB on November 21, 1996, to discuss candidate sites and a specific approach for this RNA evaluation. In addition, available site characterization data were reviewed during the preparation of this work plan. All field work will follow the health and safety procedures presented in the *Program Health and Safety Plan for the Demonstration of Remediation by Natural Attenuation* (Parsons ES, 1996) and the site-specific addendum to the program Health and Safety Plan (Parsons ES, 1997). This work plan was prepared for AFCEE and Tinker AFB.

1.1 SCOPE OF CURRENT WORK PLAN

This project is part of a large, broad-based initiative being conducted by AFCEE in conjunction with the NRMRL and Parsons ES. The intent of the RNA demonstration program is to develop a systematic process for scientifically investigating and documenting natural, subsurface chemical attenuation processes that can be factored into overall site remediation plans (Wiedemeier *et al.*, 1996a). For this reason, the work described in this work plan is directed toward the collection of data in support of demonstrating the effectiveness of RNA of CAHs and BTEX in groundwater. Data required to develop alternative remedial strategies, should RNA prove not to be a viable groundwater remedial option at one or both of these sites, also will be collected under this program. A secondary goal of this multi-site initiative is to provide a

database from multiple sites that demonstrates that natural processes of contaminant degradation often can reduce contaminant concentrations in groundwater to below acceptable cleanup standards before potential receptor exposure pathways are complete.

The specific objective for the demonstration at site FTA 2 is to investigate the degree to which CAHs dissolved in groundwater are being remediated through natural attenuation so that this information can be used by Tinker AFB to develop an effective groundwater remediation strategy. The specific objective for the demonstration at site Area A is to investigate the degree to which both CAHs and BTEX dissolved in groundwater are being remediated through natural attenuation in order to develop an effective groundwater remediation strategy. These demonstrations are not necessarily intended to fulfill specific federal or state requirements regarding site assessments, remedial action plans (RAPs), or other such mandated investigations and reports.

This work plan describes the site characterization activities to be performed by personnel from Parsons ES, the U.S. Army Corps of Engineers (USACE), and the Subsurface Protection and Remediation Division of the NRMRL (formerly the USEPA's Robert S. Kerr Environmental Research Laboratory) in support of the TS. Field activities will be performed to collect data for evaluating the effectiveness of RNA in remediating the dissolved CAH and BTEX plumes at Sites FTA 2 and Area A. The data collected during the TS will be used along with data from previous investigations to characterize contaminant and geochemical patterns at the site, and as input for analytical groundwater flow and solute transport models to make predictions of the future concentrations and extent of contamination.

Site characterization activities in support of the demonstration will include:

- Determination of preferential contaminant migration and potential receptor exposure pathways;

- Soil sample collection using hollow-stem auger drilling or Geoprobe® direct-push technology;
- Groundwater monitoring well or monitoring point installation using hollow-stem or mud-rotary drilling, or the Geoprobe®;
- Groundwater sample collection from newly installed monitoring wells or points, and existing monitoring wells;
- Soil and groundwater sample analysis; and
- Aquifer testing.

The materials and methodologies to accomplish these activities are described in Section 3.

The contaminant fate and transport modeling effort has three primary objectives: 1) predict the future extent and concentration of dissolved contaminant plumes by modeling the effects of advection, dispersion, sorption, and biodegradation; 2) assess the possible exposure of potential downgradient receptors to contaminant concentrations that exceed levels intended to be protective of human health and the environment; and 3) provide technical support for selection of RNA as a component of site remediation at regulatory negotiations, as appropriate.

Previously reported site-specific data and data collected during the supplemental site characterization activities described in this work plan will be used as input for the groundwater flow and solute transport models. Where site-specific data are not available, conservative parameter values for the types of aquifer materials present at the site will be obtained from widely accepted, published literature and used for model input. Sensitivity analyses will be conducted for the parameters that are known to have the greatest influence on the model results, and where possible, the models will be

calibrated using historical site data. If it is shown that RNA by itself is not the most appropriate remedial option, Parsons ES will recommend an appropriate groundwater remedial technology on the basis of available data.

This work plan consists of six sections, including this introduction. Section 2 presents a review of available, previously-reported, site-specific data and conceptual models for FTA 2 and Area A. Section 3 describes the proposed sampling strategy and procedures to be used for the collection of additional site characterization data. Section 4 describes the quality assurance/quality control (QA/QC) measures to be used during this project. Section 5 describes the remedial option evaluation procedure and report format. Section 6 contains the references used in preparing this document. There are four appendices to this work plan. Appendix A contains a listing of containers, preservatives, packaging, and shipping requirements for soil and groundwater analytical samples. Appendices B and C contain supplemental site data, including summarized groundwater elevation data and figures, analytical results, and geologic boring logs and monitoring well construction diagrams for Sites FTA 2 and Area A, respectively. Tinker AFB well installation standards are presented in Appendix D.

1.2 BACKGROUND

Tinker AFB is in central Oklahoma, in the southeastern portion of Oklahoma County (Figure 1.1). Tinker AFB covers approximately 5,000 acres the southeastern Oklahoma City metropolitan area. Tinker AFB was originally known as the Midwest Air Depot and began operations in July 1941. The Base was formally activated in March 1942 and serves as an international repair depot for a variety of aircraft, weapons, and engines.

Tinker AFB currently operates under a Resource Conservation Recovery Act (RCRA) Hazardous Waste Management Permit issued by the USEPA (July 1, 1991). This permit requires Tinker AFB to investigate all solid waste management units

OKLAHOMA

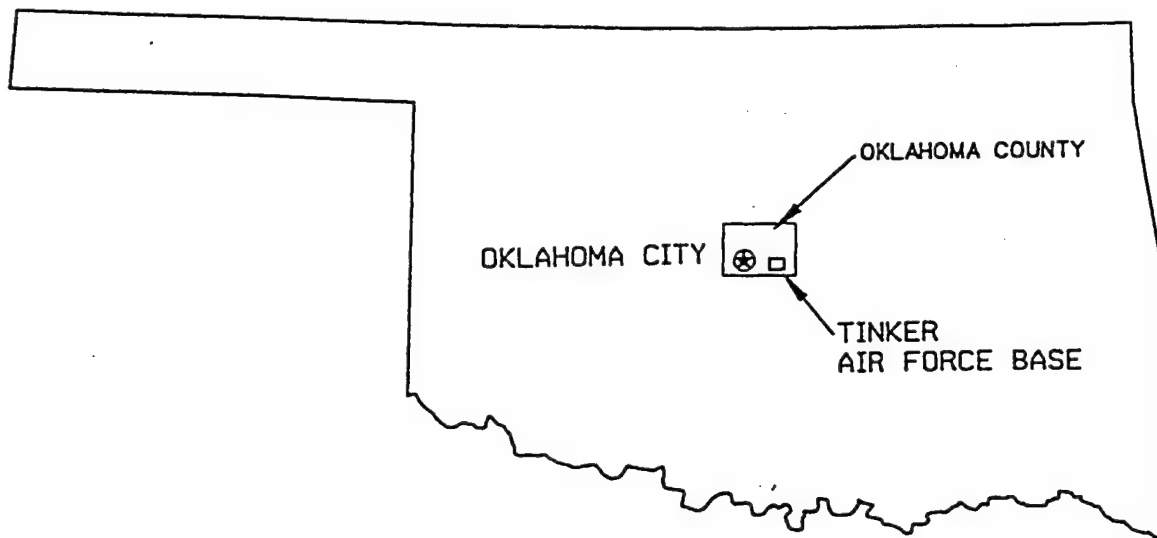


FIGURE 1.1

**LOCATION OF
TINKER AIR FORCE BASE**

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

(SWMUs) and Areas of Concern (AOCs), including FTA 2 and Area A, and to perform corrective action at those identified as posing a threat to human health or the environment. Because the Base is a Department of Defense (DOD) facility, site investigation and remediation have progressed through the stages outlined under the Installation Restoration Program (IRP). In addition, soil and groundwater investigations at Area A are mandated under Oklahoma Administrative Code (OAC) 165:25-3-76.

1.2.1 FTA 2 Background

Site FTA 2 is located in the south-central portion of the Base, west of Tower Road and south of the main northwest to southeast Runway (Figure 1.2). FTA 2 was established as a temporary, unlined pit and was used infrequently for fire training exercises between 1962 and 1966. Standard operating procedures reportedly included adding water to the pit to saturate the soil to reduce infiltration. Fuel was then brought in by tank truck, placed on top of the water, ignited, and extinguished using water and foam. Any residues were left in the pit to evaporate and infiltrate until the next fire training exercise. Available air photographs indicate that the site is currently a gently sloping, open grassy area with no visible evidence of former training practices. Records for facility operation do not exist. Therefore, data on composition, frequency, and quantity of fuel or extinguishing agents used are not available.

In 1981, a Phase I study similar to a preliminary assessment/site inspection (PA/SI) was conducted by Engineering Science, Inc. (ES, 1982) as part of the Air Force IRP. The study identified 14 potentially contaminated sites, including Site FTA 2. Based on the findings of this study, the following have been completed:

- An IRP Response Action was performed by the USACE in 1987 (USACE, 1988). Soil samples from seven boreholes, drilled to a maximum depth of 7 feet

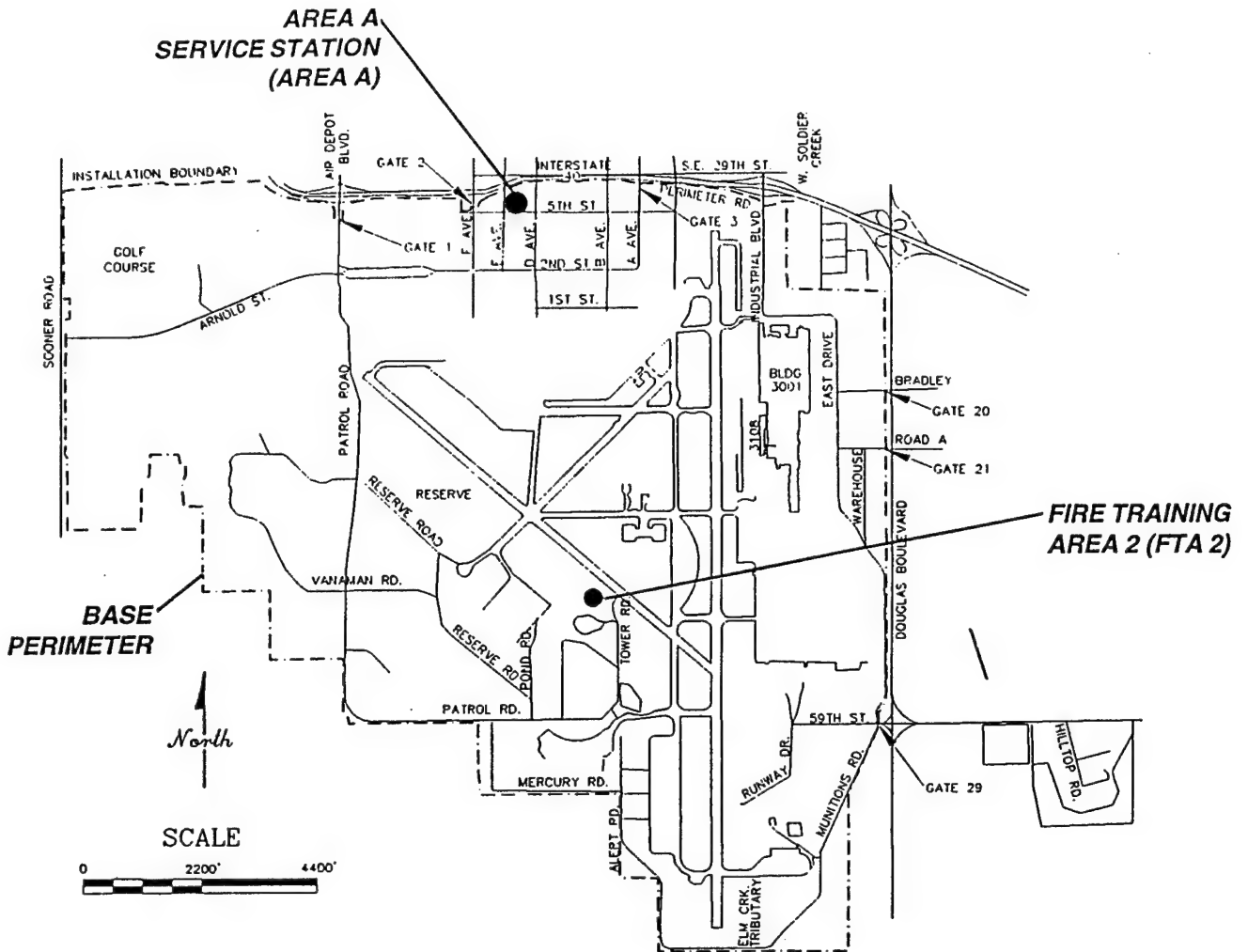


FIGURE 1.2

LOCATION OF SITES FTA 2 AND AREA A

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

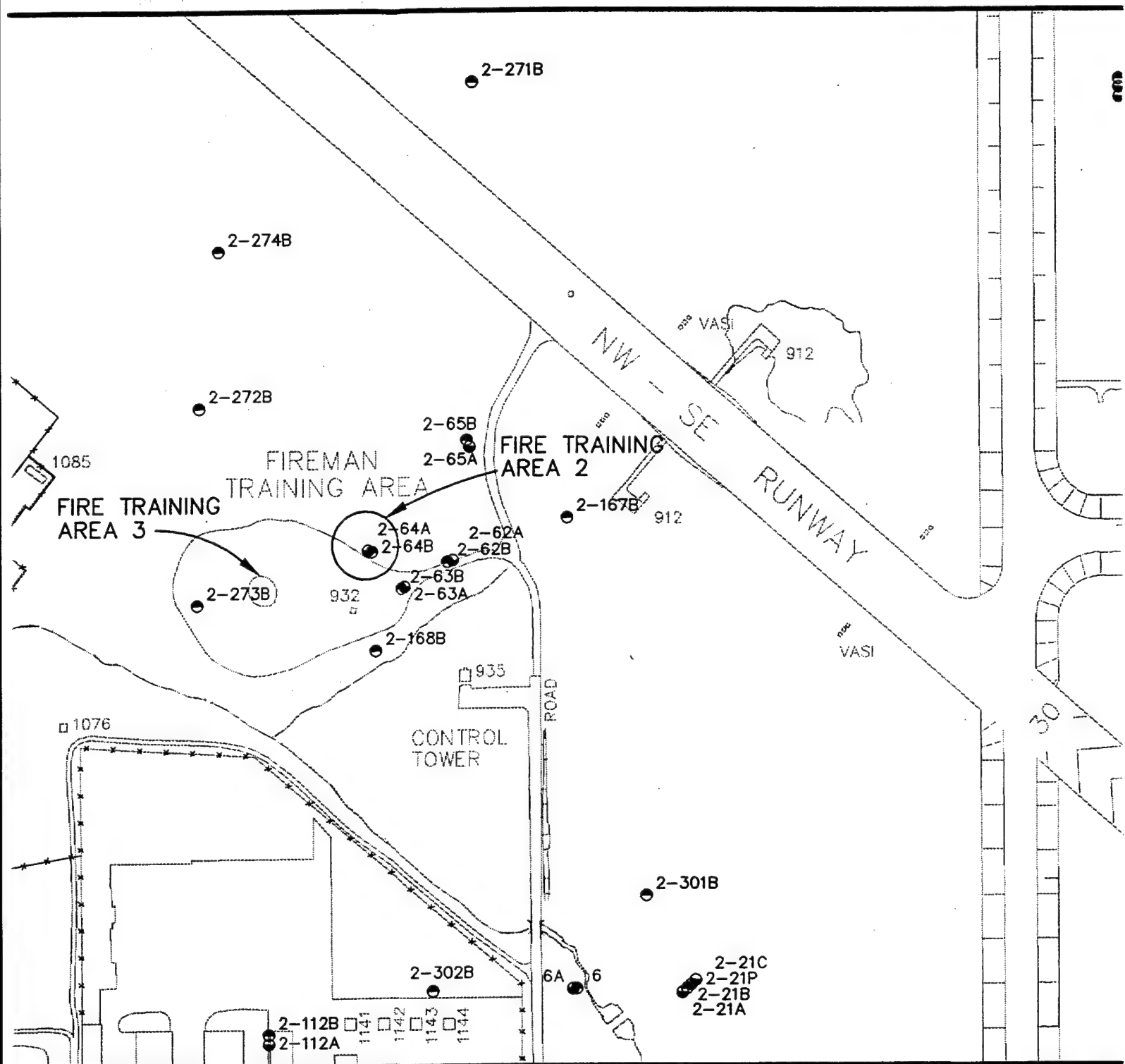
below ground surface (bgs), were analyzed for volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and total metals.

- IT Corporation (IT) conducted a Phase I RCRA Facility Investigation (RFI) from October through December 1993, including soil sampling and the installation of four monitoring well pairs (IT, 1994). Soil and groundwater samples were analyzed for VOCs, SVOCs, and metals.
- A Phase II RFI was performed by Tetra Tech, Inc. (TT), in 1995 (TT Draft Report, 1996). Soil samples were collected from 5 soil boreholes and 2 additional boreholes constructed for monitoring wells. Soil analytical results were included in the Draft Report. The monitoring wells were subsequently completed and sampled by Tinker AFB.
- Since 1995, four additional monitoring wells have been installed and sampled for groundwater quality by Tinker AFB.

There are currently 14 groundwater monitoring wells (2-62A, 2-62B, 2-63A, 2-63B, 2-64A, 2-64B, 2-65A, 2-65B, 2-167B, 2-168B, 2-271B, 2-272B, 2-273B, and 2-274B) associated with FTA 2 (Figure 1.3). Additional upgradient and cross-gradient monitoring wells associated with other sites are also available for evaluating the extent of groundwater contamination in the general area.

1.2.2 Area A Background

Area A is located at the corner of "E" Avenue and Fifth Street in the north central portion of the Base (Figure 1.2). The site was the location of the Base service station facility for military vehicles from 1942 to 1992. Two 12,000-gallon underground storage tanks (USTs), Tanks 438 and 439, were installed in 1942 to store leaded gasoline, and were later used to store unleaded fuel. Two additional USTs were installed in 1975. Tank 411 with a 10,000-gallon capacity, was used to store unleaded



2



S
FII

PARSC
ENGINE

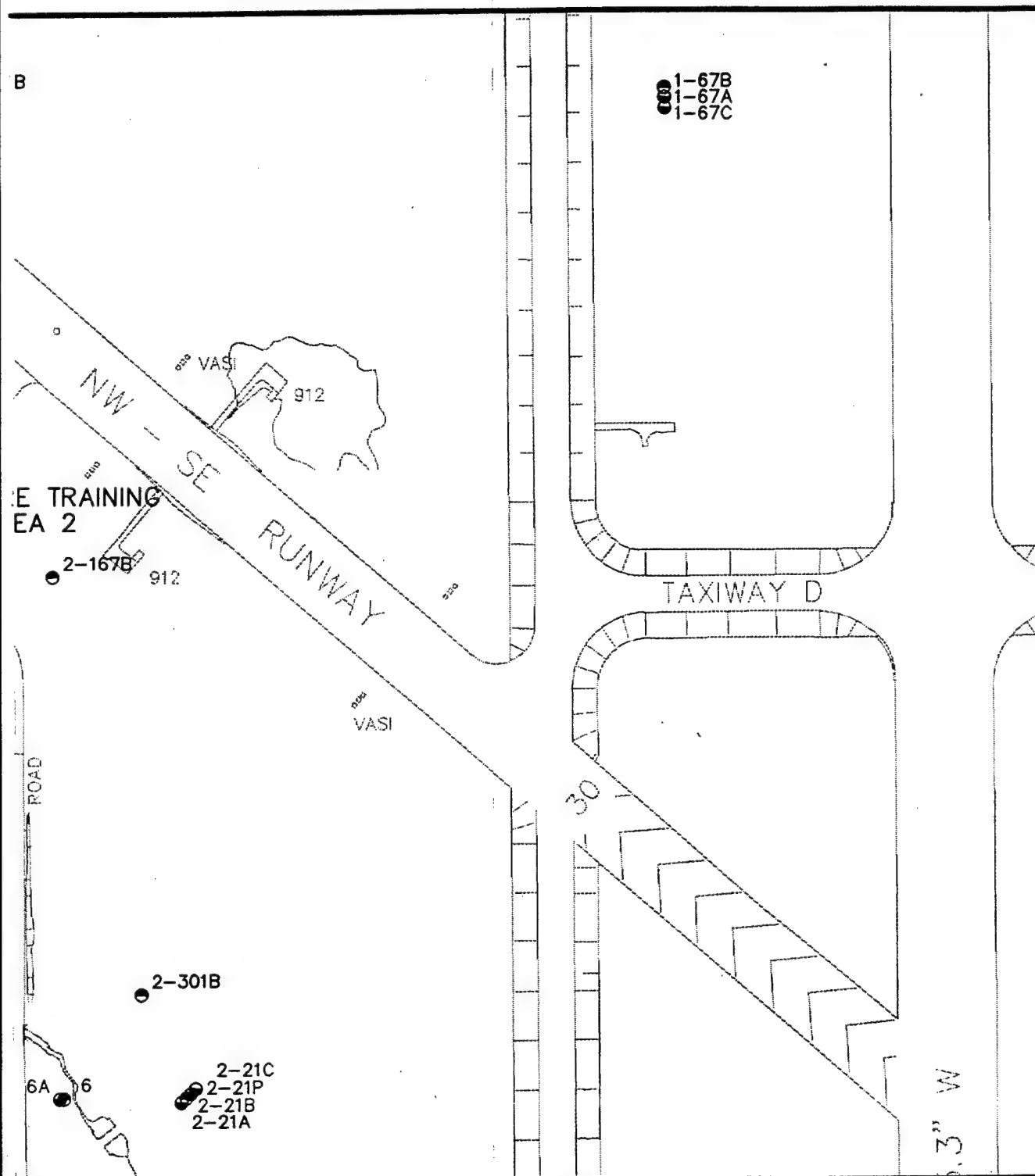


FIGURE 1.3
SITE LOCATION MAP
FIRE TRAINING AREA 2

Sites FTA 2 and Area A
 RNA TS
 Tinker AFB, Oklahoma

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

3

0 150 300 600
 FEET

gasoline, and Tank 402, of unknown size, was used to store diesel fuel. In 1978, USTs 438 and 439 were suspected of leaking and were consequently taken out of service on May 5, 1978. In 1982, Tank 411 developed a leak and was replaced with a tank of the same size and in the same location. USTs 411 and 402 were taken out of service in October 1990. The service station was officially closed in April 1991. All four USTs (Tanks 402, 411, 438, and 439) and associated piping were removed from the site in January 1996.

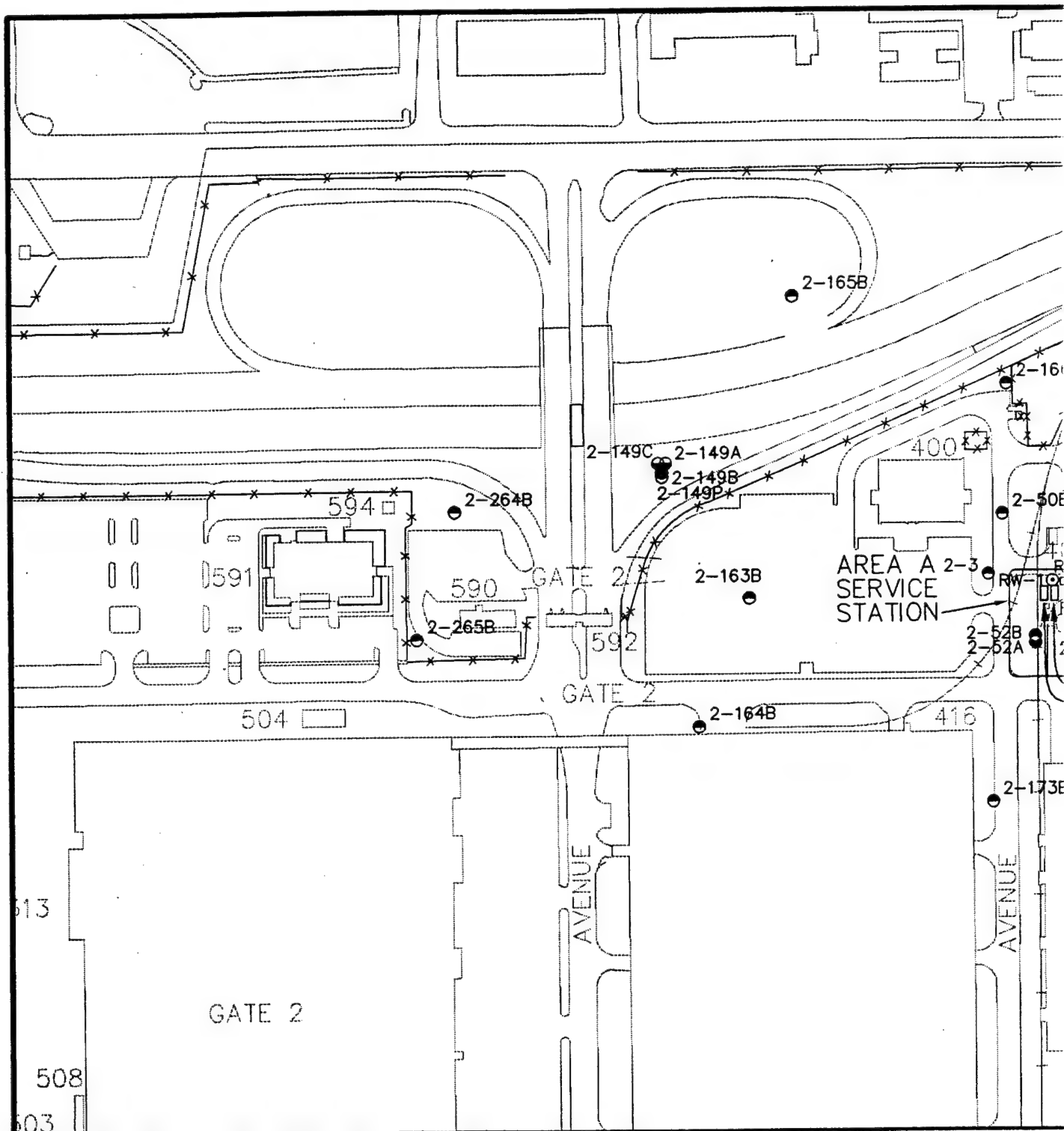
Site investigations and remedial measures were instituted in response to the leaking fuel tanks at the Area A Service Station. The following studies and remedial activities have been completed:

- An initial site investigation was performed by Environmental Recovery, Inc. (ERI) in July 1990. The investigation included five soil boreholes near Tanks 438 and 439. Soil and soil vapor samples were analyzed for BTEX, total petroleum hydrocarbons (TPH), and total lead (ERI, 1990).
- A second site investigation was performed by Water and Soil Consultants, Inc. (WSC) in 1991 and 1992 (WSC, 1992). The investigation included a soil vapor survey in February 1991. On the basis of on the vapor survey, eight soil boreholes were drilled and soil samples analyzed for BTEX, TPH, and total lead. Three of the soil boreholes were completed as monitoring wells. A free product recovery system was also installed by WSC in July 1992, consisting of three product recovery wells (WSC, 1992).
- IT conducted a soil and groundwater investigation from October 1993 to March 1994 (IT, 1995a and 1993). Three soil boreholes were drilled and soil samples collected for analysis of VOCs, SVOCs, TPH, metals, and geotechnical parameters. Three monitoring wells were installed and groundwater samples were analyzed for VOCs, SVOCs, TPH, metals, and total organic carbon (TOC).

An additional four monitoring wells were installed in November and December 1993 as deeper well pairs.

- In January 1994, existing site monitoring wells were sampled and analyzed for VOCs, SVOCs, and metals (IT, 1996).
- In January 1995, existing site monitoring wells were sampled and analyzed for VOCs, SVOCs, and metals (IT, 1996).
- A temporary groundwater probe investigation was conducted by IT from April to May 1995 (IT, 1995c). Twenty temporary groundwater points were sampled and analyzed for VOCs.
- Ten additional monitoring wells were installed in June 1995 by IT (IT, 1995b). In October 1995 existing site monitoring wells were sampled and analyzed for VOCs, SVOCs, and metals.
- Two additional monitoring wells were installed by Tinker AFB in June 1996. In August 1996 existing site monitoring wells were sampled and analyzed for VOCs, SVOCs, and metals (Tinker AFB, 1996).

There are currently 17 groundwater monitoring wells (2-2, 2-2A, 2-3, 2-4, 2-4A, 2-50B, 2-51A, 2-51B, 2-52A, 2-52B, 2-163B, 2-164B, 2-165B, 2-166B, 2-173B, 2-264B, and 2-265B) associated with Area A (Figure 1.4). Additional upgradient and cross-gradient monitoring wells associated with other sites are also available for evaluating the extent of groundwater contamination in the general area.



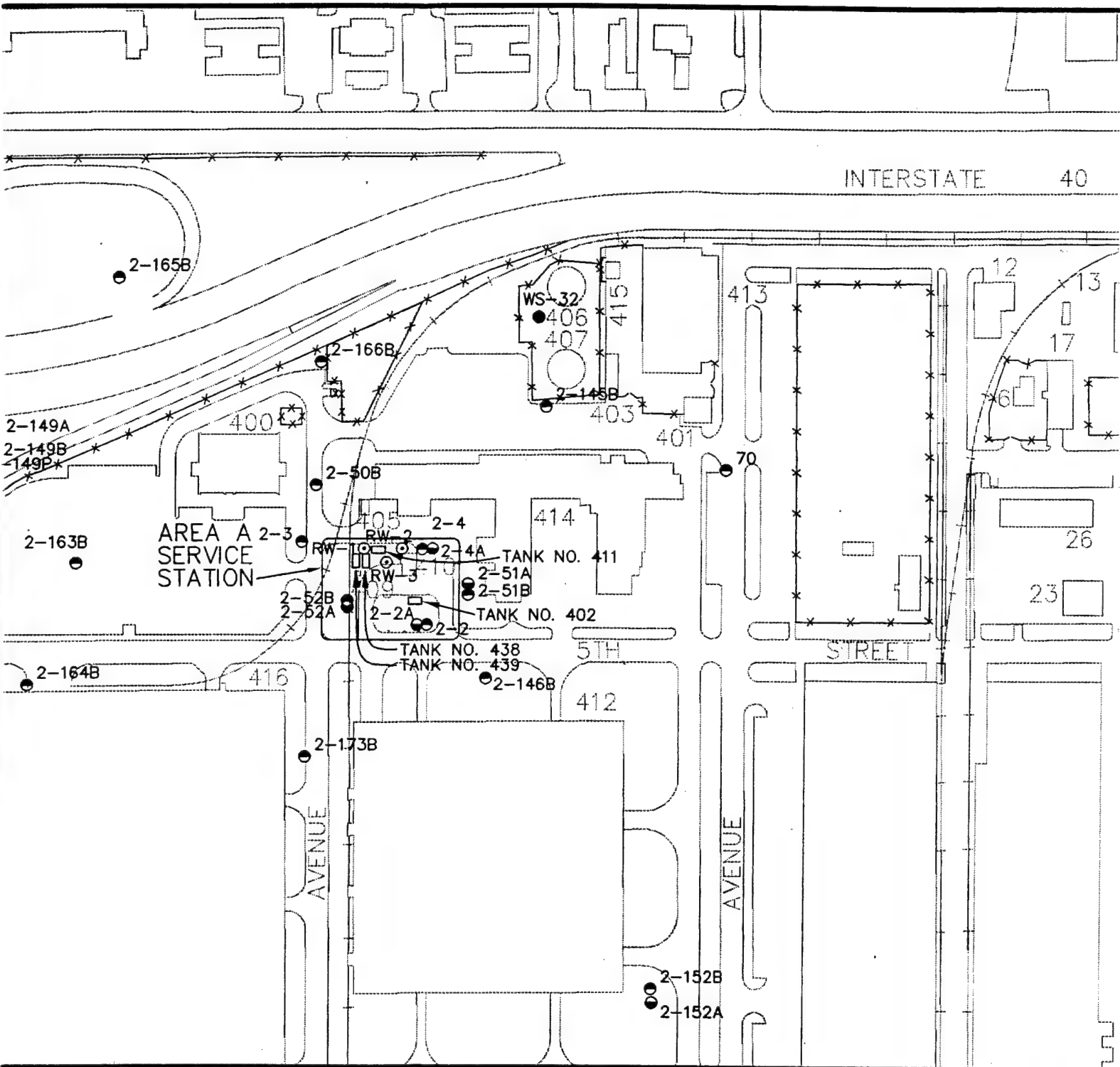
LEGEND

- 2-165B UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- 2-2A LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- ⊙ RW-1 PRODUCT RECOVERY WELL
- WS-32 WATER SUPPLY WELL

NOTE:

TANK NOS. 402, 411, 438 AND 439 HAVE BEEN REMOVED.

①



NOTE:

TANK NOS. 402, 411, 438 AND 439
HAVE BEEN REMOVED.



2

PAR
ENG

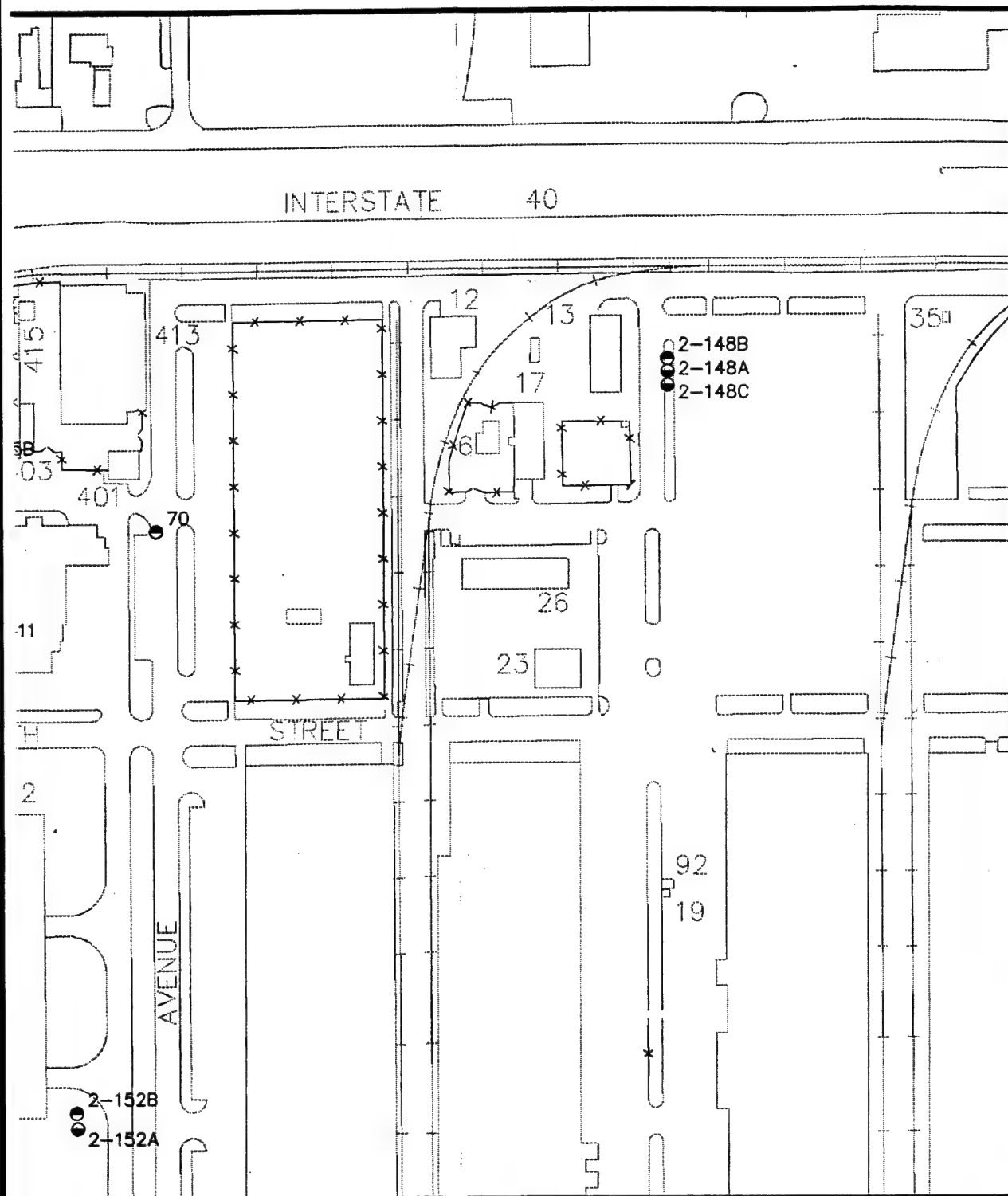


FIGURE 1.4
SITE LOCATION MAP
AREA A SERVICE STATION

Sites FTA 2 and Area A
 RNA TS
 Tinker AFB, Oklahoma

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

SECTION 2

DATA REVIEW AND CONCEPTUAL MODEL DEVELOPMENT

Site-specific data were reviewed and used to develop conceptual models for groundwater flow and contaminant transport regimes at Sites FTA 2 and Area A. The conceptual models guided the selection of sampling locations and the analytical data requirements needed to support the modeling efforts and to evaluate potential remediation technologies, including natural attenuation. Section 2.1 presents a synopsis of available site characterization data. Section 2.2 presents the preliminary conceptual groundwater flow and solute transport models that were developed on the basis of these data.

2.1 DATA REVIEW

The following sections are based upon review of data from the following sources:

- Draft Report, RCRA Facility Investigation Report for Selected Appendix I Sites at Tinker Air Force Base, OK (TT, 1996);
- Final Report, Investigation for Soil and Groundwater Cleanup Report, Area A Service Station, Tinker Air Force Base, Oklahoma (IT, 1996);
- Temporary Groundwater Probe Investigation Report, Area A Service Station, Tinker Air Force Base, Oklahoma (IT, 1995c); and
- Final Report, Phase I RCRA Facility Investigation for Appendix I Sites, Volume I, SWMU-8, Fire Training Area 2 (IT, 1994).

2.1.1 Topography, Surface Hydrology, and Climate

Tinker AFB is located in central Oklahoma and topography varies from almost level to gently rolling. The local relief is a result of dissection by erosional activity and stream channel development. Ground surface elevations at Tinker AFB range from 1,190 feet above the National Geodetic Vertical Datum (NGVD) near the northwest corner where Crutcho Creek intersects the Base boundary, to 1,320 feet NGVD at Area D, located east of the main installation. Topographic maps of Sites FTA 2 and Area A at Tinker AFB are presented as Figures 2.1 and 2.2, respectively.

Surface water runoff from the Base primarily drains to diversion structures and then to intermittently flowing surface streams. The north and west portions of the Base drain to Crutcho Creek, a tributary of the North Canadian River. Kuhlman Creek also collects drainage from the northwest portion of the Base and discharges into Crutcho Creek north of the Base. The northeast portion of the Base is drained primarily by tributaries of Soldier Creek, which is also a tributary of Crutcho Creek. Two small unnamed intermittent tributaries of Elm Creek cross installation boundaries south of the main runway, and generally do not receive significant quantities of Base runoff due to site grading designed to preclude such drainage. These streams, when flowing, extend to Stanley Draper Lake, approximately one-half mile south of the Base.

In the area of FTA 2, topography slopes gently to the southwest, towards Crutcho Creek, with elevations ranging from 1240 to 1250 feet NGVD. The sloping topography is modified by an incised channel of a southwest-flowing tributary to Crutcho Creek. The channel of this tributary is approximately 5 to 10 feet below the grade of the surrounding terrain. Surface water run-off at FTA 2 travels southeast to this southwest-draining tributary. The tributary emerges from a culvert located approximately 200 feet east of FTA 2, after draining an area occupied by industrial facilities on the east side of the airfield.

NW-SE RUNWAY

000

1250

FIRE TRAINING AREA 2

FIRE TRAINING AREA 3

1240

1250

CRUTCHO CREEK

1076

935

CONTROL
TOWER

1240

1240

LEGEND

- X-X- FENCE
- DRAINAGE
- 1240 — CONTOUR INTERVAL



0 200
FEET

FIGURE 2.1

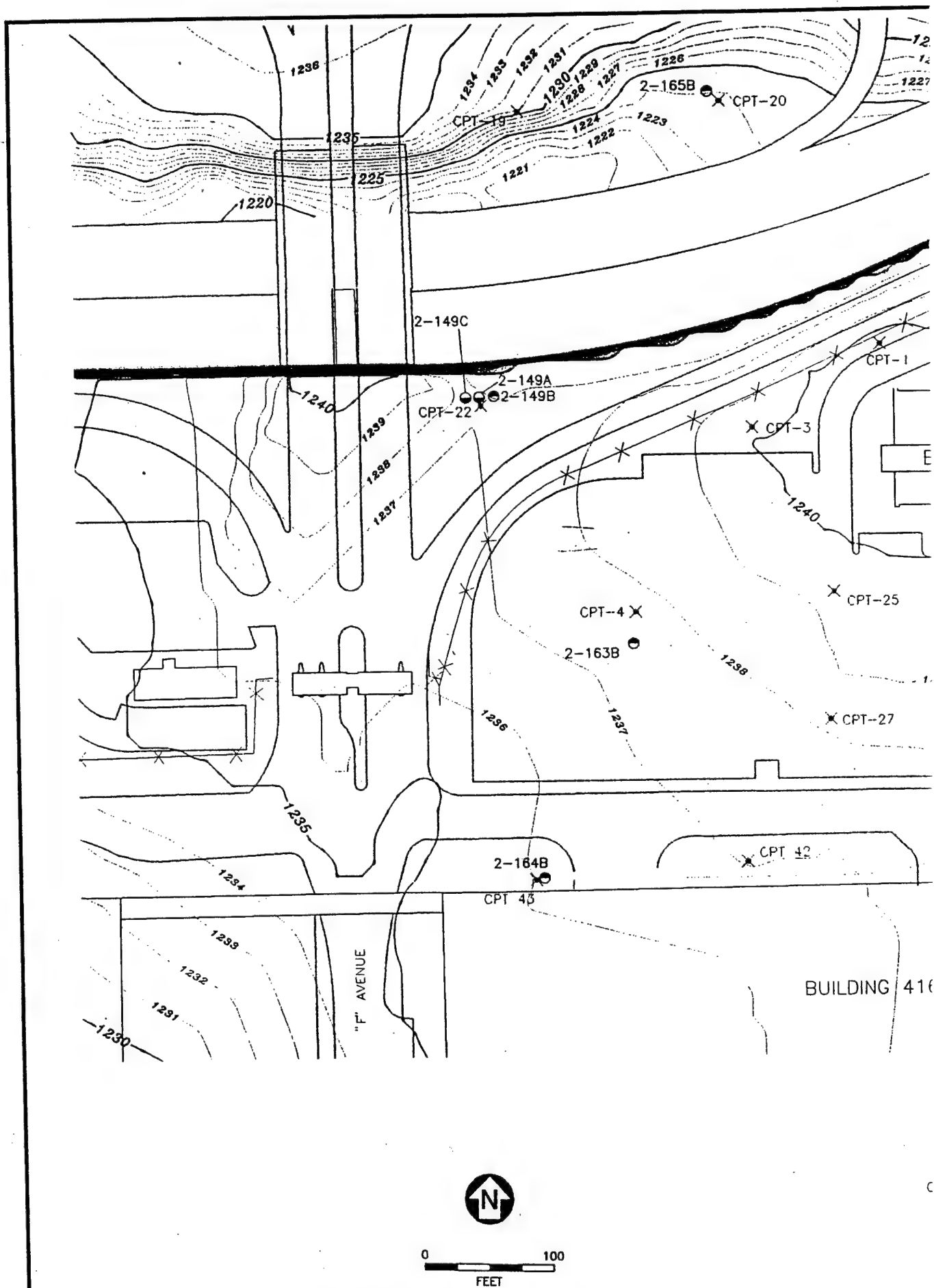
**TOPOGRAPHIC MAP OF
FIRE TRAINING AREA 2**

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

Source: IT, 1994.



Sources: Tinker AFB, 1997; and IT, 1996.



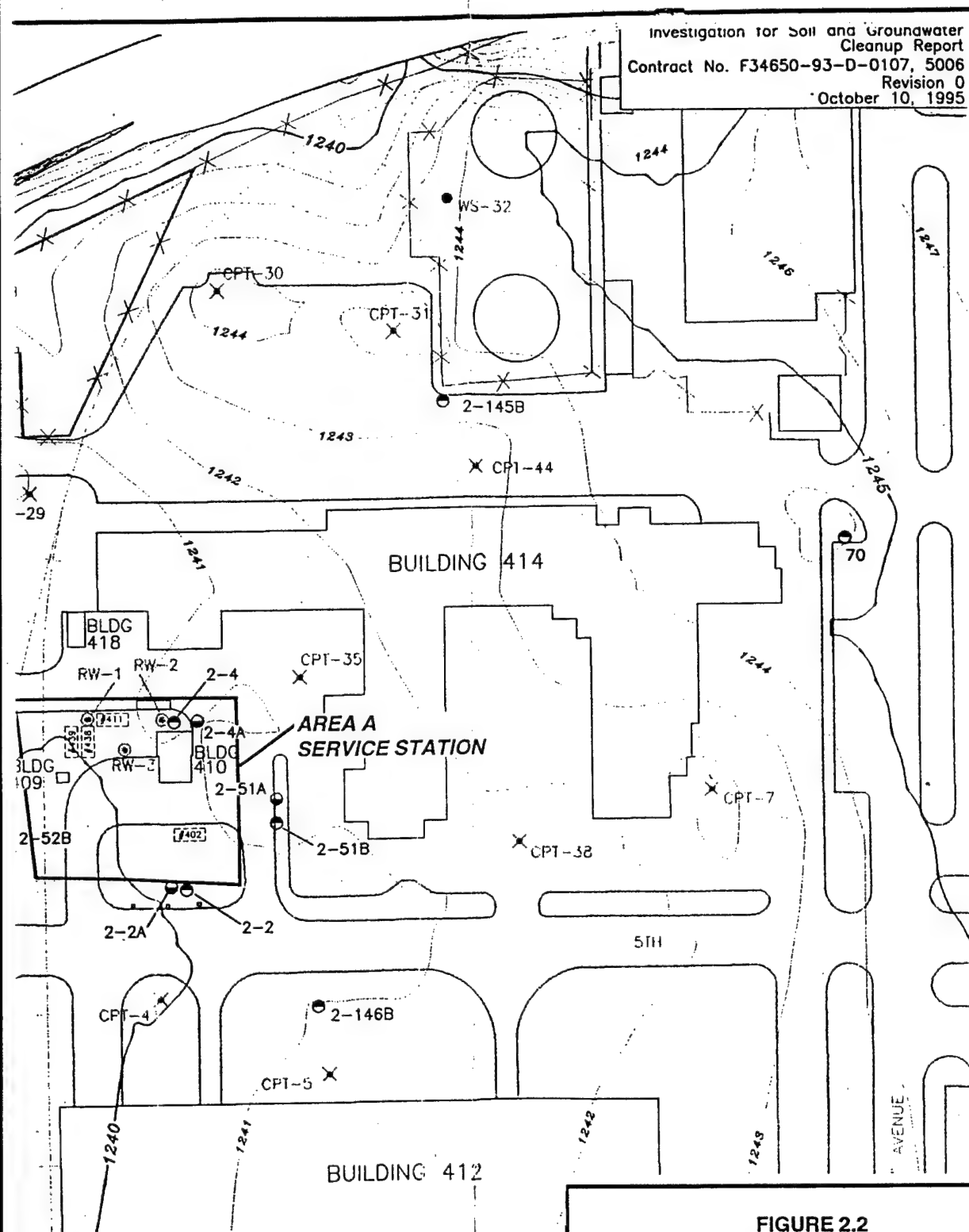


FIGURE 2.2

TOPOGRAPHIC MAP OF AREA A SERVICE STATION

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

AND

PROBE
NUMBER

MONITORING WELL

MONITORING WELL

402

LOCATION OF INACTIVE/CLOSED
UNDERGROUND STORAGE TANK

* *

FENCE

-1240-

5 FOOT CONTOUR INTERVAL
(FEET - DATUM: NGVD)

- 1239

1 FOOT CONTOUR INTERVAL
(FEET - DATUM: NGVD)

In Area A the ground surface slopes to the west and elevations range from 1230 to 1247 feet NGVD. Surface drainage from the site is directed into Kuhlman Creek to the west of the site. Kuhlman Creek discharges into Crutch Creek north of the Base.

The climate in central Oklahoma is continental, and is characterized by cold winters, hot summers, and moderate rainfall. Precipitation averages 33 inches per year. Annually, potential evaporation usually exceeds precipitation. Maximum evaporation occurs during June, July, and August.

2.1.2 Overview of Geology and Hydrogeology

The following sections provide an overview of regional and site geology and hydrogeology.

2.1.2.1 Regional Geology

Tinker AFB is located within the Central Redbed Plain Section of the Central Lowland Physiographic Province, which is tectonically stable. No major faults or fracture zones have been mapped near Tinker AFB. Tinker AFB is underlain by several thousand feet of sedimentary strata that range in age from Cambrian to Permian and overlie a Precambrian igneous basement. The major lithologic units in the area of Tinker AFB are relatively flat-lying and have a regional westward dip of approximately 40 feet per mile (ft/mile) (Bingham and Moore, 1975).

Geologic units that outcrop at Tinker AFB consist of, in descending order, Quaternary Alluvium, the Hennessey Group, and the Garber Sandstone (Table 2.1, Figure 2.3). The Wellington Formation crops out to the east of Tinker AFB. Quaternary alluvium and terrace deposits overlie bedrock in and near present-day stream valleys. Quaternary deposits consist of unconsolidated soils from weathered bedrock, eolian sands, and interfingering lenses of fluvial sands, silts, clays and gravels. Terrace deposits are exposed where stream valleys downcut through older

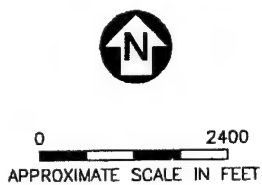
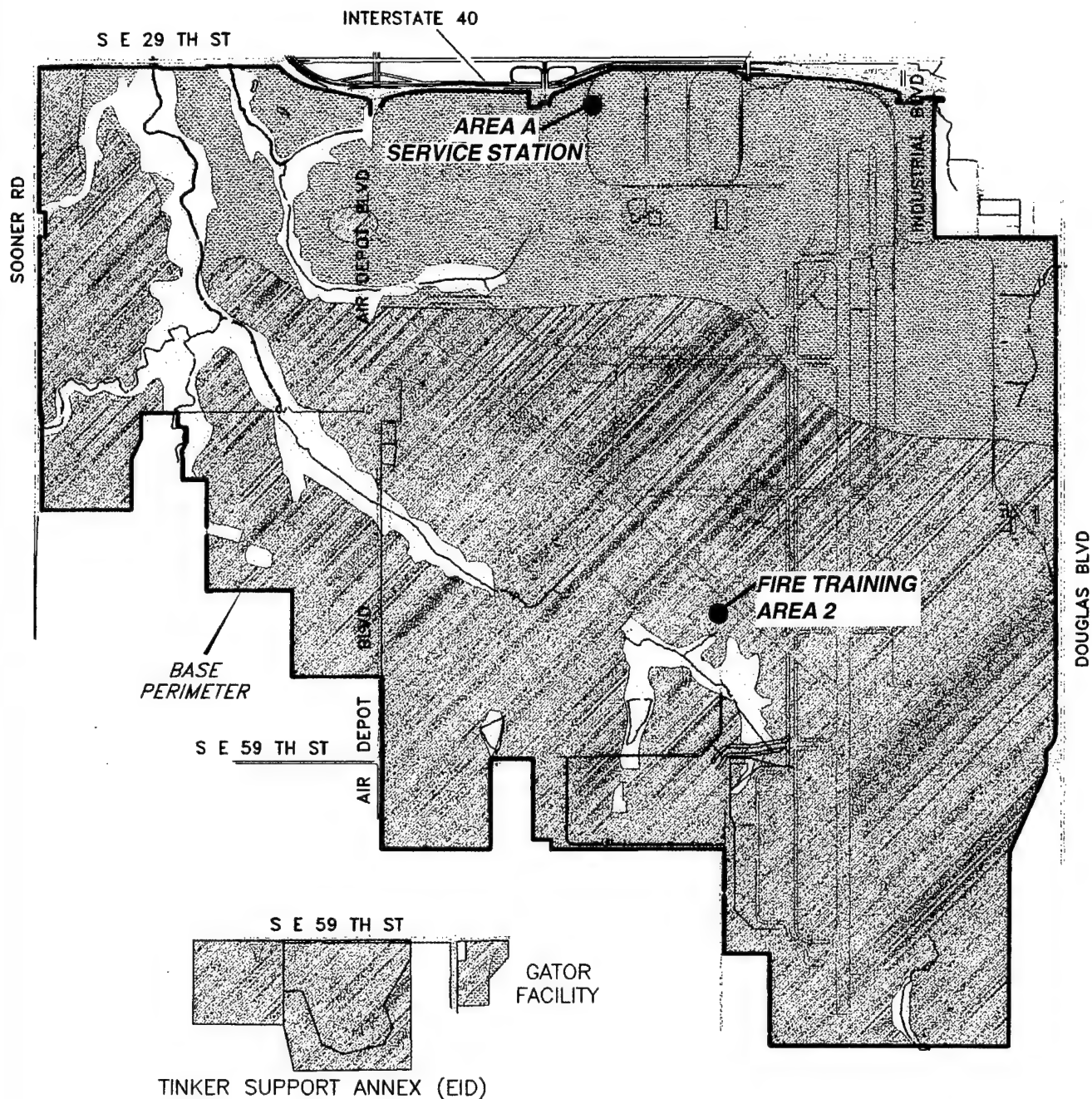
TABLE 2.1
MAJOR GEOLOGIC UNITS IN THE VICINITY OF TINKER AFB
SITES FTA2 AND AREA A RNA TS
TINKER AFB, OKLAHOMA

System	Series	Stratigraphic unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
Q U A T E R N A Y	P L E I S T O C E N E	Alluvium	0-70	Unconsolidated, with interfingering lenses of sand, silt, clay, and gravel in flood plains and stream channels.	Moderately permeable. Yields small to moderate quantities of water in valleys of larger streams. Water is very hard, but suitable for most uses, unless contaminated by industrial wastes or oil field brines
	A N D R E C E N T	Terrace deposits	0-100	Unconsolidated, with interfingering lenses of sand, silt, gravel, and clay that occur at one or more levels above flood plains and principal streams.	Moderately permeable. Where deposits have sufficient saturated thickness, they are capable of yielding moderate quantities of water to wells. Water is moderately hard to very hard, but less mineralized than water in other aquifers. Suitable for most uses unless contaminated by oil field brines.

TABLE 2.1 (Continued)
MAJOR GEOLOGIC UNITS IN THE VICINITY OF TINKER AFB
SITES FTA2 AND AREA A RNA TS
TINKER AFB, OKLAHOMA

System	Series	Stratigraphic unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
P E R M	L	Hennessey	700	Deep-red clay shale containing thin beds of red sandstone and white or greenish bands of sandy or limey shale. Forms relatively flat to gently rolling grass-covered prairie.	Poorly permeable. Yields meager quantities or very hard, moderately to highly mineralized water to shallow domestic and stock wells. In places, water contains elevated levels of sulfate.
	O	Group (includes Kingmen			
	W	Siltstone and			
	E	Fairmont Shale)			
	R				
I A N	P				
	E				
	R				
	M				
	I				
A N	A	Garber Sandstone	500 ±	Deep-red to reddish-orange sandstone, massive and cross-bedded and interfingering with red shale and siltstone.	Poorly to moderately permeable. Important source of groundwater in Cleveland and Oklahoma counties. Yields small to moderate quantities of water to deep wells; heavily pumped for industrial and municipal uses in the Norman and Midwest City areas. Water from shallow wells hard to very hard; water from deep wells moderately hard to soft. Lower part contains water too salty for domestic and most industrial uses.
	N				
		Wellington Formation	500 ±	Deep-red to reddish-orange massive and cross-bedded fine-grained sandstone interbedded with red, purple, maroon, and gray shale. Base of information not exposed in the area.	

Source: Modified from Wood and Burton, 1968.



EXPLANATION




-  HENNESSEY GROUP
-  GARBER SANDSTONE/
WELLINGTON FORMATION
-  ALLUVIUM

FIGURE 2.3

SURFACE GEOLOGIC MAP TINKER AIR FORCE BASE

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

Source: Tinker AFB, 1991; IT, 1996.

strata, leaving them topographically higher than present day valley floors. Alluvial sediments range in thickness from less than a foot to nearly 20 feet.

The Hennessey Group, Garber Sandstone, and Wellington Formation are Permian in age (230 to 280 million years ago), and consist of a conformable sequence of sands, silts, and clays with lenticular beds that vary in thickness over short horizontal distances. Because of similar lithologies and lack of fossils or key beds, the Garber Sandstone and the Wellington Formation are difficult to distinguish and are informally grouped as the Garber-Wellington Formation. Together these units are approximately 900 feet thick beneath Tinker AFB.

The Hennessey Group outcrops on the central, southern, and western portions of the Base, generally to the west and south of Crutch Creek (Figure 2.3). The Hennessey Group is composed of the Kingman Siltstone and the Fairmont Shale (Miser *et al.*, 1954; Bingham and Moore, 1975). The Hennessey Group thins from approximately 70 feet in the southwest part of the Base towards its erosional edge across the northeastern part of the Base. The contact between the Hennessey group and the underlying Garber Sandstone is often difficult to distinguish. The unit is composed of red shale and thin beds of fine sandstone.

The Garber Sandstone outcrops across the northern, central, and eastern portions of the Base, and is generally covered by a thin veneer of soil or alluvium up to 20 feet thick (Figure 2.3). The Garber Sandstone conformably underlies the Hennessey Group and consists of dominantly fine sandstone, with lesser amounts of siltstone and shale. Outcrops north of the base are characterized by small to medium channels with cross-bedded sandstones featuring cut and fill structures. Geophysical and lithologic logs of soil boreholes drilled on Base indicate that 65 to 70 percent of the Garber Sandstone and Wellington Formation are composed of sandstone. The sandstones are typically fine to very fine grained, friable, and poorly cemented. However, the sandstone

intervals are locally cemented, typically at the base of sandstone lenses, by quartz, carbonate or iron-bearing minerals. These cemented intervals form horizons resistant to drilling. Shale intervals are generally discontinuous, and range in thickness from a few inches to 40 feet.

2.1.2.2 Regional Hydrogeology

Tinker AFB overlies a regional source of potable water, the Central Oklahoma aquifer system. The productive formations of the aquifer include the Permian redbeds, including parts of the Permian Garber Sandstone and Wellington Formation, and Quaternary alluvium and terrace deposits. The Central Oklahoma aquifer has been classified as a Class IA aquifer by the State of Oklahoma, signifying that it is an irreplaceable source of public water supply (State of Oklahoma Water Resources Board, 1994). Water from the Central Oklahoma aquifer is used for municipal, industrial, domestic and agricultural purposes. Tinker AFB presently derives most of its water from a system of 26 operable water wells constructed generally along the east and west margins of the base, and from the Oklahoma City Water Department. All Base wells are completed in the Garber-Wellington Formation at depths of 400 to 1,100 feet.

Groundwater in the Central Oklahoma aquifer is derived primarily from precipitation infiltrating outcrops of the geologic units. Infiltration of surface waters from streams crossing the outcrops is believed to be a minor source of recharge to the aquifer (Parkhurst *et al.*, 1993). Tinker AFB is located in the outcrop area of the Garber Sandstone and is therefore in the recharge zone of the aquifer.

The groundwater system at Tinker AFB has been divided into four hydrogeologic zones: the Hennessey Water-Bearing Zone (HWBZ), the Upper and Lower Saturated Zones (USZ and LSZ), and the Producing Zone of the regional Garber-Wellington aquifer. The HWBZ occurs within the Hennessey Group and is perched above the USZ over the southwest portion of the Base. The LSZ and USZ are regionally considered to

be in the upper third of the Garber-Wellington aquifer and generally are present at depths of less than 200 feet bgs. The Producing Zone generally is considered to be greater than 200 bgs, and is used for water supply at Tinker AFB.

Figure 2.4 shows the locations of regional hydrogeologic cross-sections A-A' (Figure 2.5) and B-B' (Figure 2.6). The HWBZ is perched within the Hennessey Group on the southwestern portion of the Base. The USZ generally behaves as a water table aquifer in the eastern part of the Base, but could be confined in localized portions of the Base where intra-USZ clay lenses intersect the USZ piezometric surface. The depth to the USZ water table ranges from zero feet bgs northeast and east of the Base to approximately 40 feet bgs in the southwest part of the Base. The regional stratigraphic dip of 0.0076 feet per foot (ft/ft) to the west-southwest produces a general westward groundwater flow pattern in the USZ. Hydraulic gradients in the USZ across Tinker AFB range from 0.0034 to 0.018 ft/ft and average 0.0076 ft/ft. A low-permeability zone, characterized by high clay content and well-cemented silts and sands in the USZ, acts as an aquitard between the USZ and the LSZ.

The LSZ is considered one hydraulic unit from the USZ/LSZ aquitard to an approximate depth of 200 feet bgs. Due to variations in topography, the top of the LSZ is found at depths of 10 to 100 feet bgs. The LSZ extends east of the Base beyond the limits of the USZ and is the shallowest groundwater zone screened in off-Base wells. Across the central portion of the Base, the vadose zone at the top of the LSZ disappears where the overlying clay layer dips below the surface of the LSZ. At some locations the LSZ may be confined by the overlying clay layer. A low-permeability zone at the base of the LSZ (characterized by high clay content) acts as an aquitard between the LSZ and the Producing Zone. The Producing zone extends from 200 to greater than 900 feet bgs and is under confined conditions.

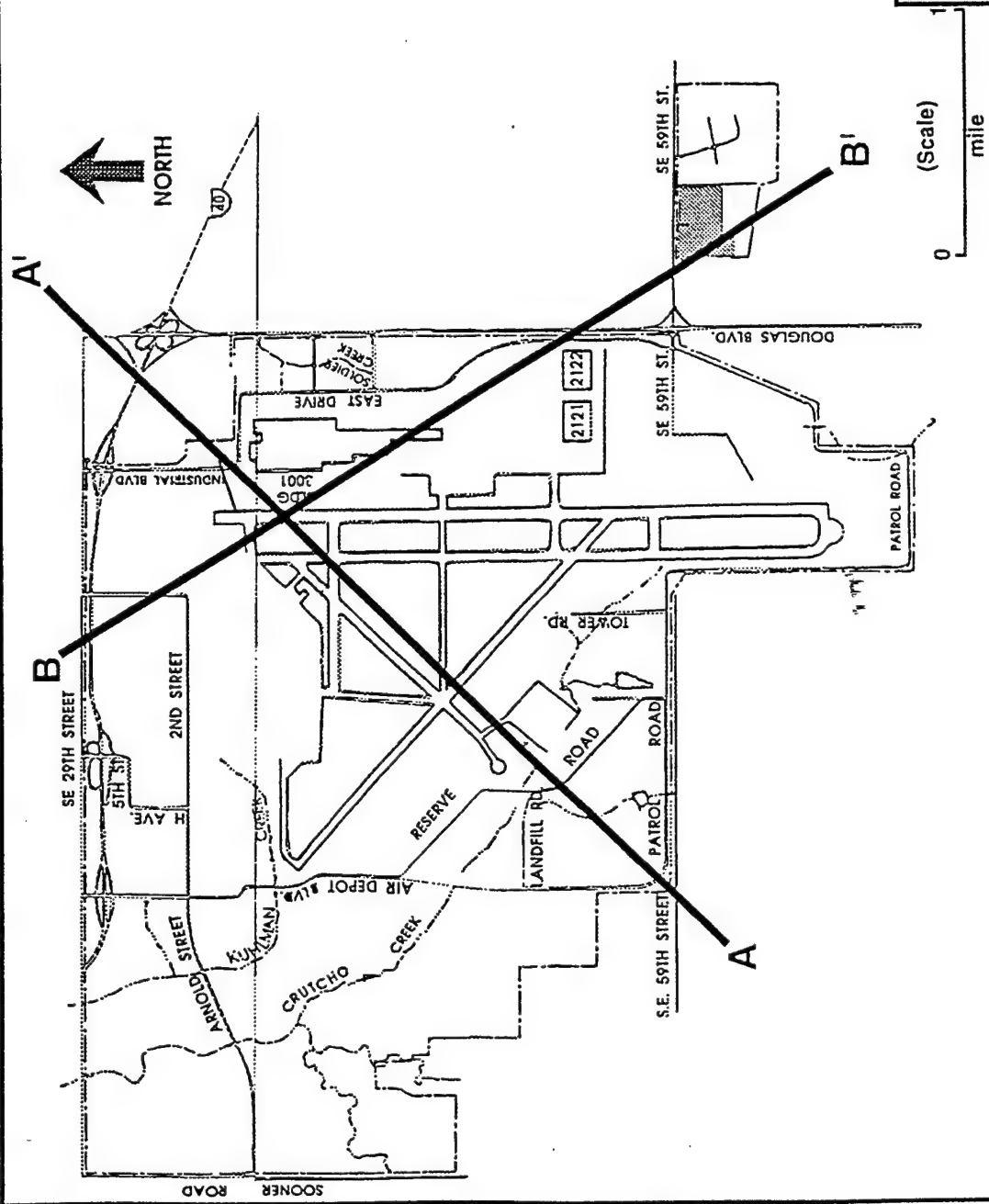


FIGURE 2.4

LOCATION OF HYDROGEOLOGIC
CROSS-SECTIONS A-A' AND B-B'

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**
Denver, Colorado

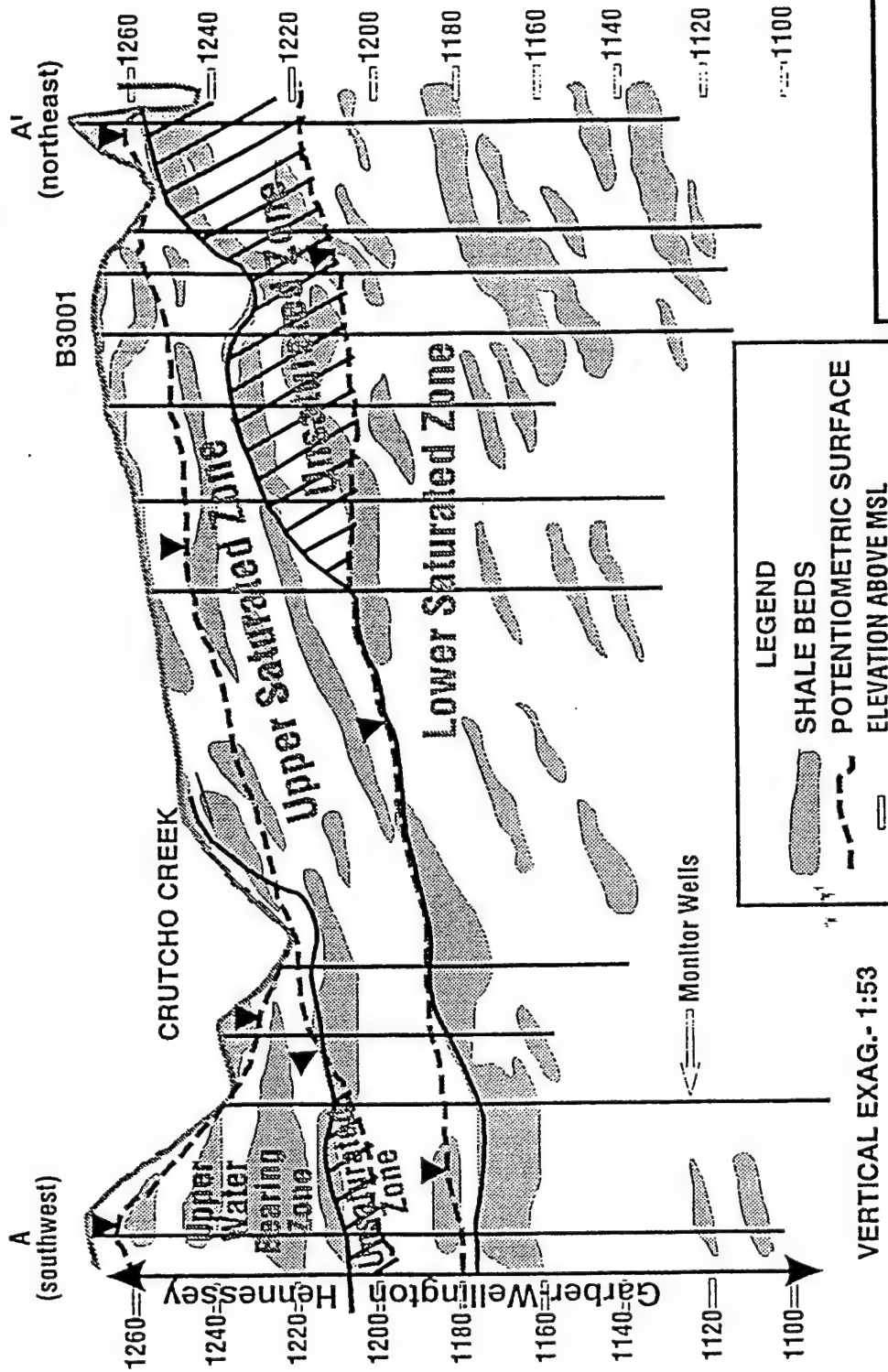


FIGURE 2.5

HYDROGEOLOGIC CROSS-SECTION A-A'

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**
Denver, Colorado

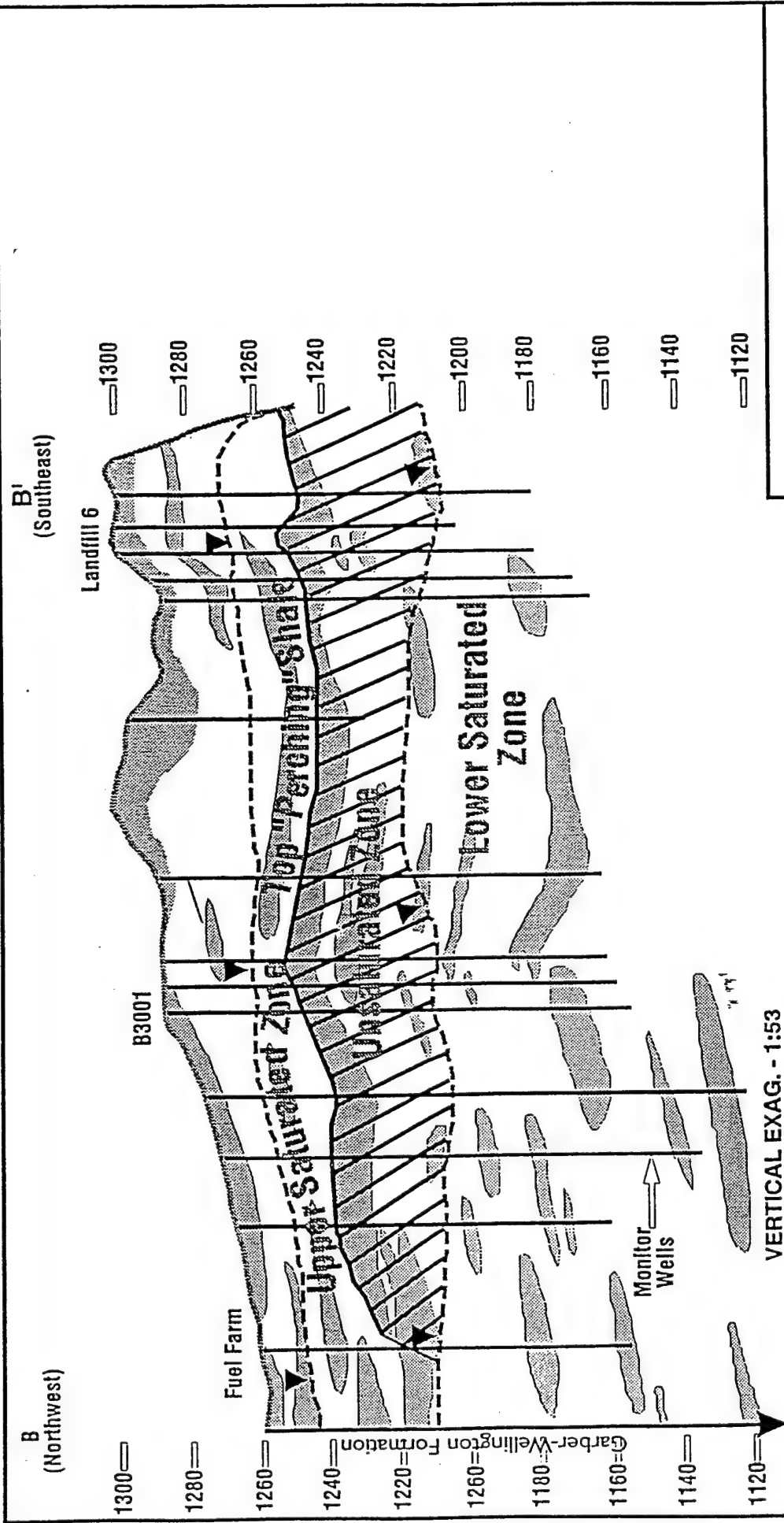
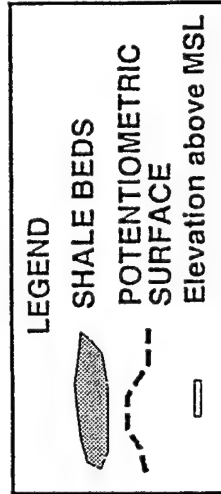


FIGURE 2.6

HYDROGEOLOGIC CROSS-SECTION B-B'

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**
Denver, Colorado

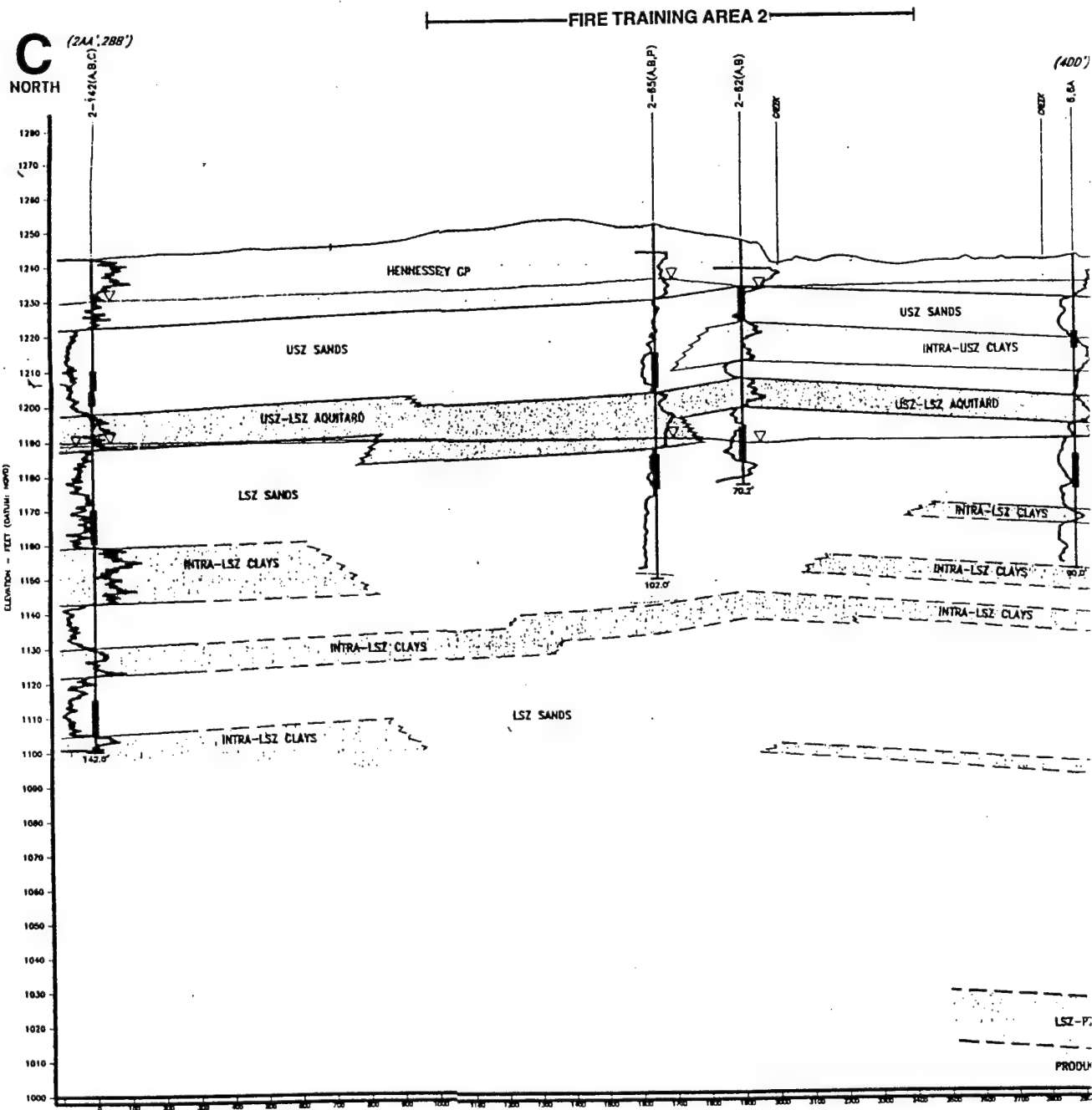


2.1.2.3 FTA 2 Geology and Hydrogeology

The geology at FTA 2 closely matches the description of the regional geology. FTA 2 hydrogeologic cross-section C-C' (Figure 2.7) illustrates the stratigraphy through the center of the site perpendicular to the direction of groundwater flow. Approximately 8 to 15 feet of reddish silty clay or clayey silt of the Hennessey Group overlies sands of the Garber Sandstone. The Garber Sandstone consists of fine-grained sands with a number of discontinuous silt and clay lenses. A regional interval with high clay content and cemented silt (USZ-LSZ Aquitard) separates the Garber Sandstone into two distinct hydrogeologic intervals. The aquitard is found at an approximate depth of 40 to 45 feet bgs.

The hydrogeology at FTA 2 also closely matches regional conditions. The unconfined USZ potentiometric surface coincides approximately with the Hennessey Group/Garber Sandstone (USZ sands) contact, generally within 8 feet of the contact in the Hennessey Group, and 7 to 15 feet bgs. A perched HWBZ exists approximately 1000 feet to the south of FTA 2. Groundwater elevations and monitoring well completion data are listed in Table 2.2. Figure 2.8 is a groundwater potentiometric map for the USZ based on data from September 1996 (Tinker AFB, 1996). Flow direction in the immediate vicinity of FTA 2 is generally towards the west, with local variations due to lithologic, topographic, or surface (tributary) features. The groundwater gradient in the USZ is approximately 0.0037 ft/ft. The flow direction and gradient in the USZ are consistent with groundwater flow direction and gradient data observed in 1994 (IT, 1994). The base of the USZ is a layer of hard siltstone traceable across the area at a depth of approximately 40 to 45 feet bgs.

The top of the LSZ coincides approximately with the base of the USZ-LSZ aquitard at a depth of approximately 50 to 60 feet bgs. Where the LSZ potentiometric surface lies beneath the base of the USZ-LSZ aquitard, the LSZ is under unconfined conditions (Figure 2.7). Locally the LSZ may be confined where the USZ-LSZ aquitard dips



NOTES:

- ABBREVIATIONS USED ON CROSS-SECTIONS:
 HWBZ → HENNESSEY WATER BEARING ZONE
 USZ → UPPER SATURATED ZONE
 LSZ → LOWER SATURATED ZONE
 LLSZ → LOWER-LOWER SATURATED ZONE
 PZ → PRODUCING ZONE
- "X" WELL IDENTIFIER INDICATES THAT WELL WAS DRILLED, THEN PLUGGED AND ABANDONED.
- "P" IDENTIFIER INDICATES DEEP PILOT HOLE DRILLED FOR GEOPHYSICAL LOGGING PURPOSES.

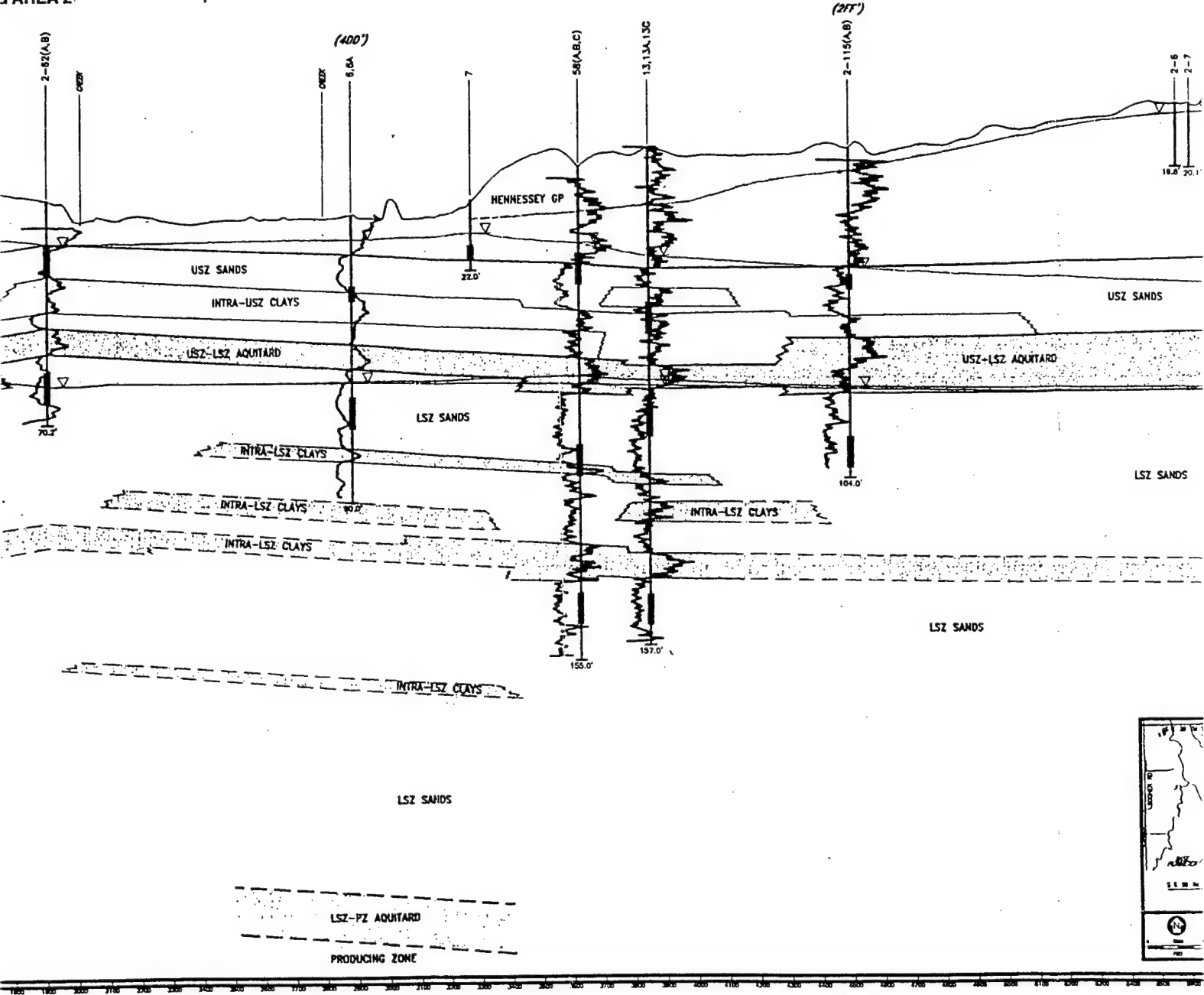
EXPLANATION

- (2AA)
 D → CROSS-SECTION TIE POINT(S)
 WELL IDENTIFICATION
 WELL
 WATER LEVEL ELEVATION (JULY, 1995)
 SCREENED INTERVAL
 GAMMA LOG
 45.0' TOTAL DEPTH DRILLED
 * DIGITIZED ANALOG GAMMA LOGS

- ▽ HENNESSEY WATER BEARING ZONE
 --- HWBZ POTENTIOMETRIC SURFACE
 ▽ UPPER SATURATED ZONE
 --- USZ POTENTIOMETRIC SURFACE
 ▽ LOWER SATURATED ZONE
 --- LSZ POTENTIOMETRIC SURFACE

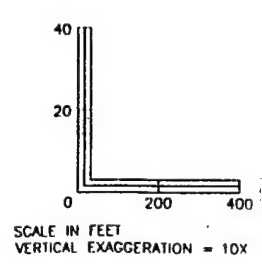
- ▽ PRODUCING ZONE
 --- PZ PC
 --- DRY WELL
 --- HYDROCARBON
 --- LITHOLOGY
 --- POTENTIOMETRIC BOUNDARIES, AND DASHED WHERE I

3 AREA 2



- ▽ HENNESSEY WATER BEARING ZONE
 - HWBZ POTENTIOMETRIC SURFACE
 - ▽ UPPER SATURATED ZONE
 - USZ POTENTIOMETRIC SURFACE
 - ▽ LOWER SATURATED ZONE
 - LSZ POTENTIOMETRIC SURFACE
 - ▬ PRODUCING ZONE
 - PZ POTENTIOMETRIC SURFACE
 - DRY WELL
 - HYDROGEOLOGIC BOUNDARIES
 - LITHOLOGIC CONTACTS
- NOTE:
POTENTIOMETRIC SURFACES, HYDROGEOLOGIC BOUNDARIES, AND LITHOLOGIC CONTACTS DASHED WHERE INFERRED.

- HENNESSEY GROUP (GP)
 - USZ SANDS
 - INTRA-USZ CLAYS
 - USZ AQUITARD
 - LSZ SANDS
 - INTRA-LSZ CLAYS
 - LSZ-PZ AQUITARD
 - PRODUCING ZONE
- GARBER-WELLINGTON AQUIFER



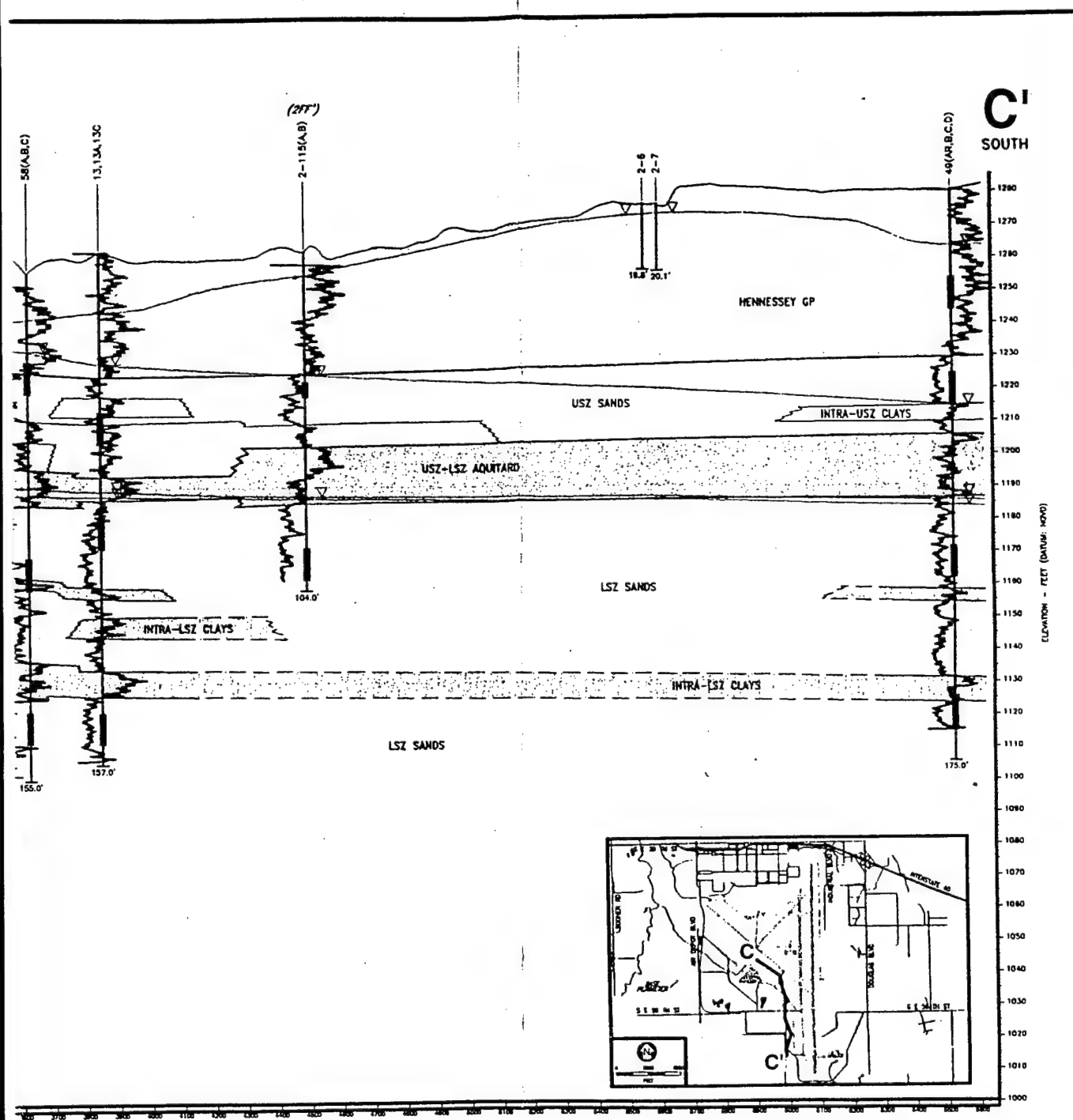


FIGURE 2.7
HYDROGEOLOGIC
CROSS-SECTION C-C'
FTA 2

Sites FTA 2 and Area A
 RNA TS
 Tinker AFB, Oklahoma

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

TABLE 2.2
MONITORING WELL SUMMARY AND
SEPTEMBER 1996 GROUNDWATER ELEVATIONS, FTA 2
SITES FTA-2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

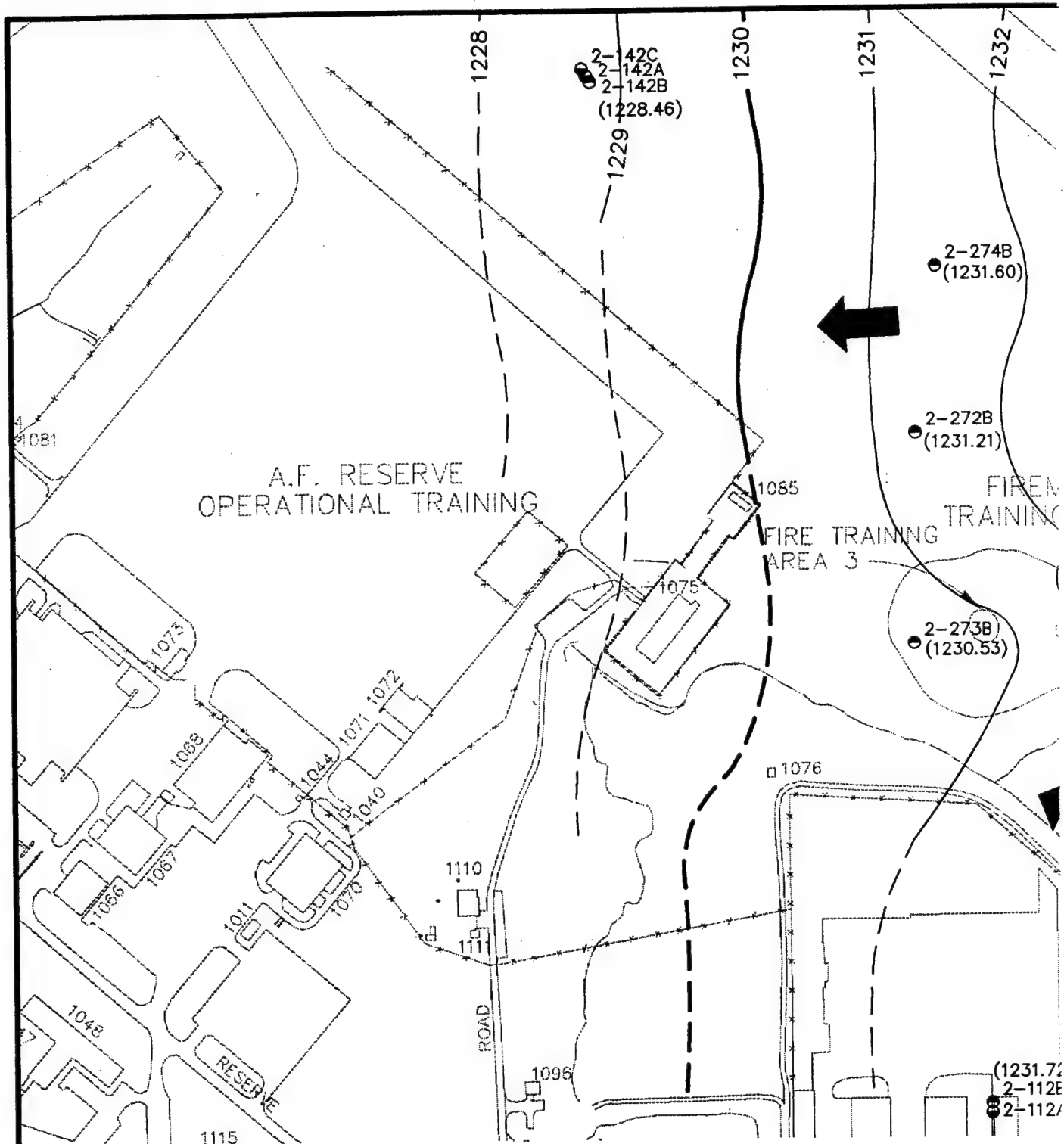
Well/Borehole Identification	Site Code	Aquifer Zone	Completion Date	Well Diameter (Inches)	Screened Interval (Feet bgs) ^{a/}	Elevation Datum (Feet msl) ^{b/}	Elevation Datum	Ground Surface Elevation	Survey Northing (State Plane)	Survey Easting (State Plane)	Depth to Water Sept. 1996 (ft bwc) ^{c/}	Elevation of Water Table - Sept. 1996 (Feet msl)
Monitoring Wells - Upper Saturated Zone												
2-62B	FT22	USZ	11/9/93	2.0	14-24	1245.94	Top PVC	1245.94	150444.52	2182140.56	14.24	1231.70
2-63B	FT22	USZ	11/8/93	2.0	18-23	1243.28	Top PVC	1243.28	150386.11	2182035.36	11.83	1231.45
2-64B	FT22	USZ	11/9/93	2.0	16-26	1245.59	Top PVC	1245.59	150467.40	2181967.76	13.88	1231.71
2-65B	FT22	USZ	11/5/93	2.0	37-47	1250.81	Top PVC	1250.81	150712.88	2182183.20	17.20	1233.61
2-167B	FT22	USZ	8/8/95	4.0	19-29	1250.70	Top PVC	1247.70	150539.81	2182408.35	16.07	1234.63
2-168B	FT22	USZ	8/8/95	4.0	10-20	1243.00	Top PVC	1240.10	150249.00	2181976.69	12.12	1230.88
2-271B	FT22	USZ	8/8/96	4.0	36-46	1252.13	Top PVC	1252.41	151494.42	2182196.43	18.55	1233.58
2-272B	FT22	USZ	8/9/96	4.0	25-35	1248.91	Top PVC	1249.38	150784.70	2181581.74	17.70	1231.21
2-273B	FT22	USZ	6/18/96	4.0	17-27	1238.42	Top PVC	1238.92	150351.11	2181576.36	7.89	1230.53
2-274B	FT22	USZ	7/25/96	4.0	37-42	1248.32	Top PVC	1248.77	151126.23	2181625.92	16.72	1231.60
1-67B	OT01	USZ	5/22/93	2.0	34-44	1264.15	Top PVC	NA ^{d/}	NA	NA	25.26	1238.82
2-142B	BW	USZ	5/19/95	4.0	32-42	1242.09	Top PVC	1242.45	NA	NA	13.56	1228.46
2-112B	LF15	USZ	1/20/95	4.0	30-40	1250.89	Top PVC	1247.65	NA	NA	19.10	1231.72
2-301B	LF15	USZ	6/17/96	4.0	16-26	1265.71	Top PVC	1263.19	150500.39	2176072.65	9.42	1256.29
2-302B	LF15	USZ	7/24/96	4.0	27-37	1249.15	Top PVC	1246.46	149491.80	2182106.79	16.91	1232.24
2-160B	ST07	USZ	6/5/95	4.0	5-15	1253.56	Top PVC	1250.99	NA	NA		
Monitoring Wells - Lower Saturated Zone												
2-62A	FT22	LSZ	11/29/93	2.0	54-64	1246.21	Top PVC	1246.21	150447.89	2182152.17	57.57	1188.64
2-63A	FT22	LSZ	11/23/93	2.0	53-63	1243.39	Top PVC	1243.39	150389.96	2182043.02	54.89	1188.50
2-64A	FT22	LSZ	11/22/93	2.0	56-66	1246.05	Top PVC	1246.05	150470.21	2181959.37	57.48	1188.57
2-65A	FT22	LSZ	11/19/93	2.0	66-76	1250.98	Top PVC	1250.98	150698.28	2182189.88	61.55	1189.43
1-67A	OT01	LSZ	5/22/93	2.0	75-85	1264.37	Top PVC	NA	NA	NA	71.05	1193.25
1-67C	OT01	LLSZ	5/22/93	2.0	109-119	1264.19	Top PVC	NA	NA	NA	71.07	1193.05
2-142A	BW	LSZ	5/19/95	4.0	72-82	1241.76	Top PVC	1242.30	NA	NA	52.98	1188.71
2-112A	LF15	LSZ	1/23/95	4.0	86-96	1251.41	Top PVC	1248.03	NA	NA	64.48	1186.86

^{a/} feet bgs indicates elevation in feet below ground surface.

^{b/} feet msl indicates elevation in feet above mean sea level.

^{c/} bwc indicates depth measured below top of well casing.

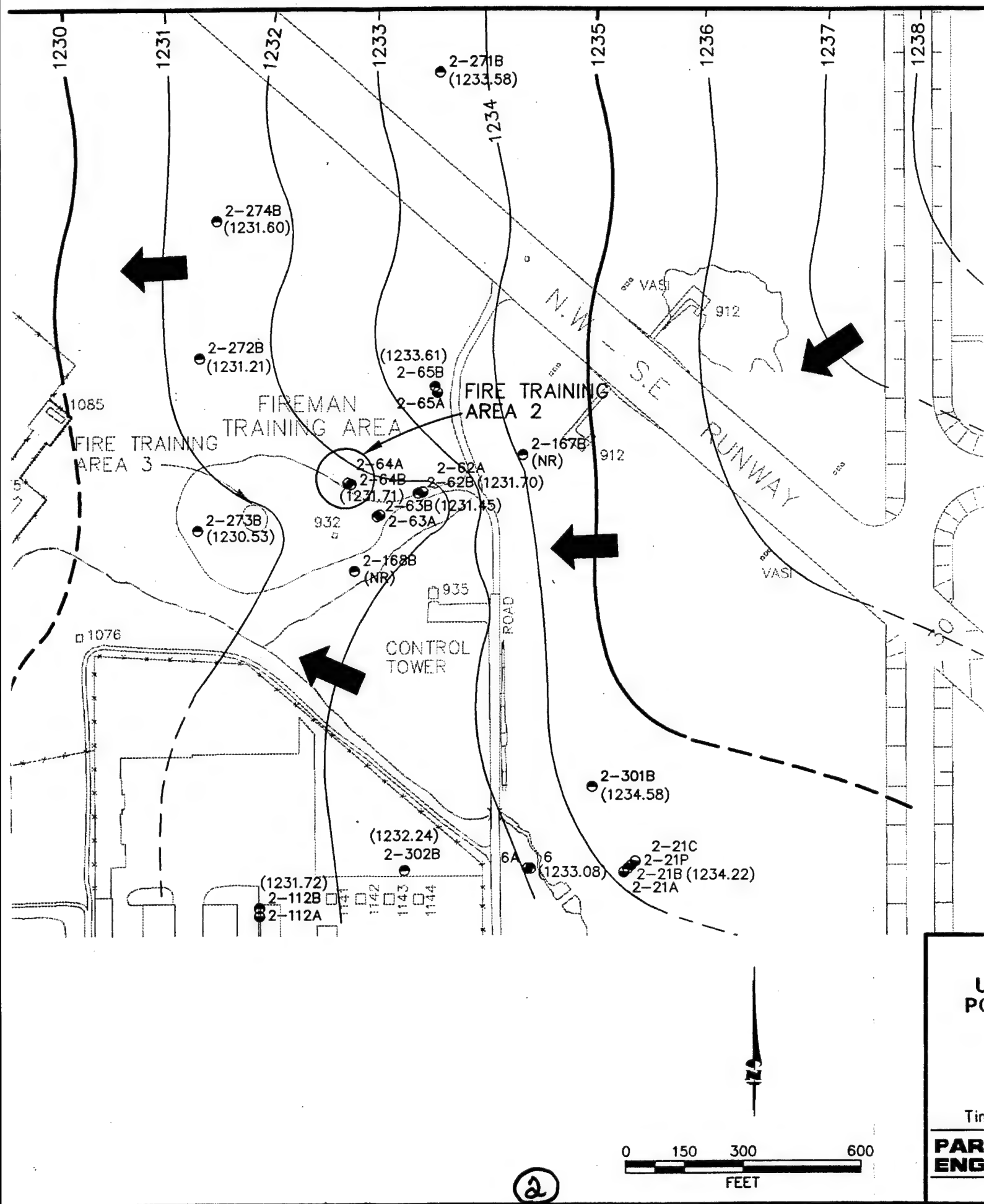
^{d/} NA indicates the data are not currently available.



LEGEND

- 2-142B ● UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- 2-142A ● LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- ← DIRECTION OF GROUNDWATER FLOW
- 1231- LINE OF EQUAL GROUNDWATER ELEVATION (FEET MSL), DASHED WHERE INFERRED

①



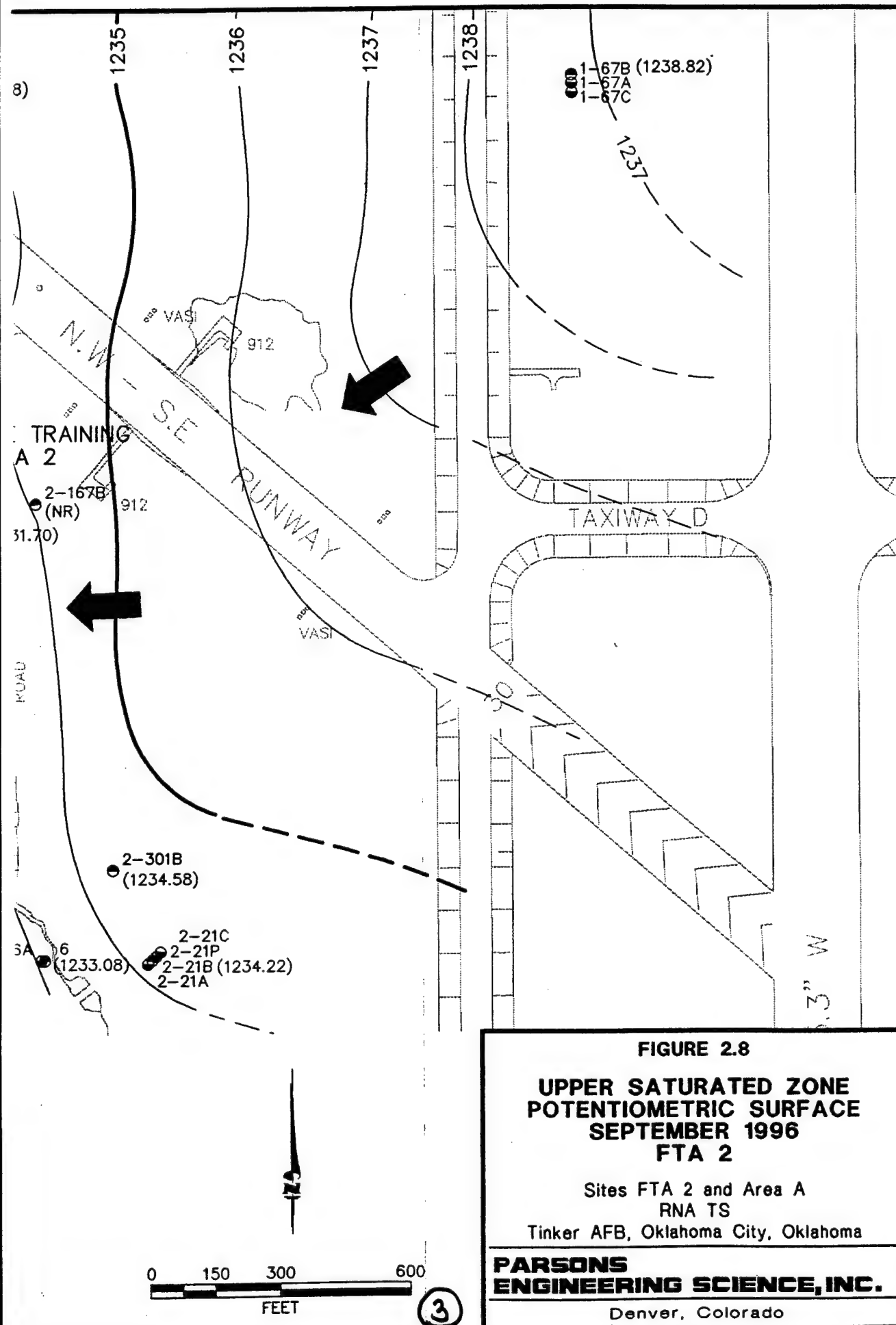


FIGURE 2.8

**UPPER SATURATED ZONE
POTENTIOMETRIC SURFACE
SEPTEMBER 1996
FTA 2**

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma City, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

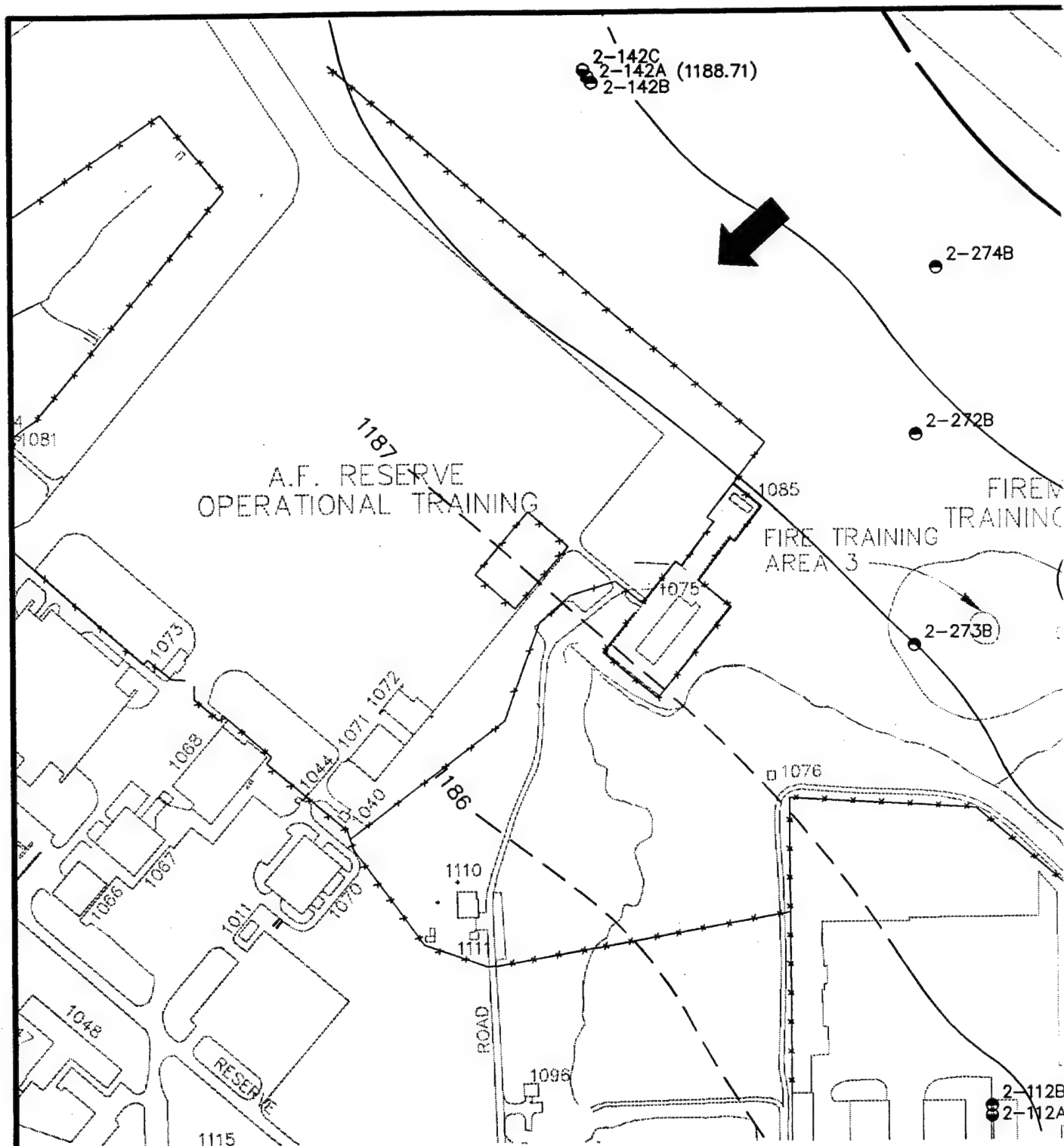
beneath the LSZ potentiometric surface. Figure 2.9 is a groundwater potentiometric surface map for the LSZ based on data from September 1996 (Tinker AFB 1996 database). Groundwater flow in the LSZ is towards the southwest at an approximate gradient of 0.0023 ft/ft. The flow direction and gradient in the USZ are consistent with groundwater flow direction and gradient data observed in 1994 (IT, 1994).

Available geological boring logs, monitoring well completion records, and slug test data for FTA 2 are included in Appendix B.





2.1.2.4 Area A Geology and Hydrogeology

The geology at Area A matches the description of the regional geology. Area A hydrogeologic cross-sections D-D' (Figure 2.10) and E-E' (Figure 2.11) illustrate the stratigraphy through the center of the site perpendicular (D-D') and parallel (E-E') to the direction of groundwater flow. The Garber Sandstone is present from ground surface to the maximum depth drilled (86 feet bgs). Approximately 10 to 20 feet of clay, silty clay, and clayey silt (intra-USZ clays) are present at the surface. Beneath this clay unit is approximately 15 to 28 feet of fine-grained sands, with discontinuous silt and clay lenses peripheral to the area immediately beneath the Area A service station. A regional interval with high clay content and cemented silt (USZ-LSZ Aquitard) separates the Garber Sandstone into two distinct hydrogeologic intervals. This interval is present at an approximate depth of 35 feet bgs. The aquitard at Area A is approximately 5 to 7 feet thick, and overlies fine-grained sands and intra-LSZ clays and clayey silts.

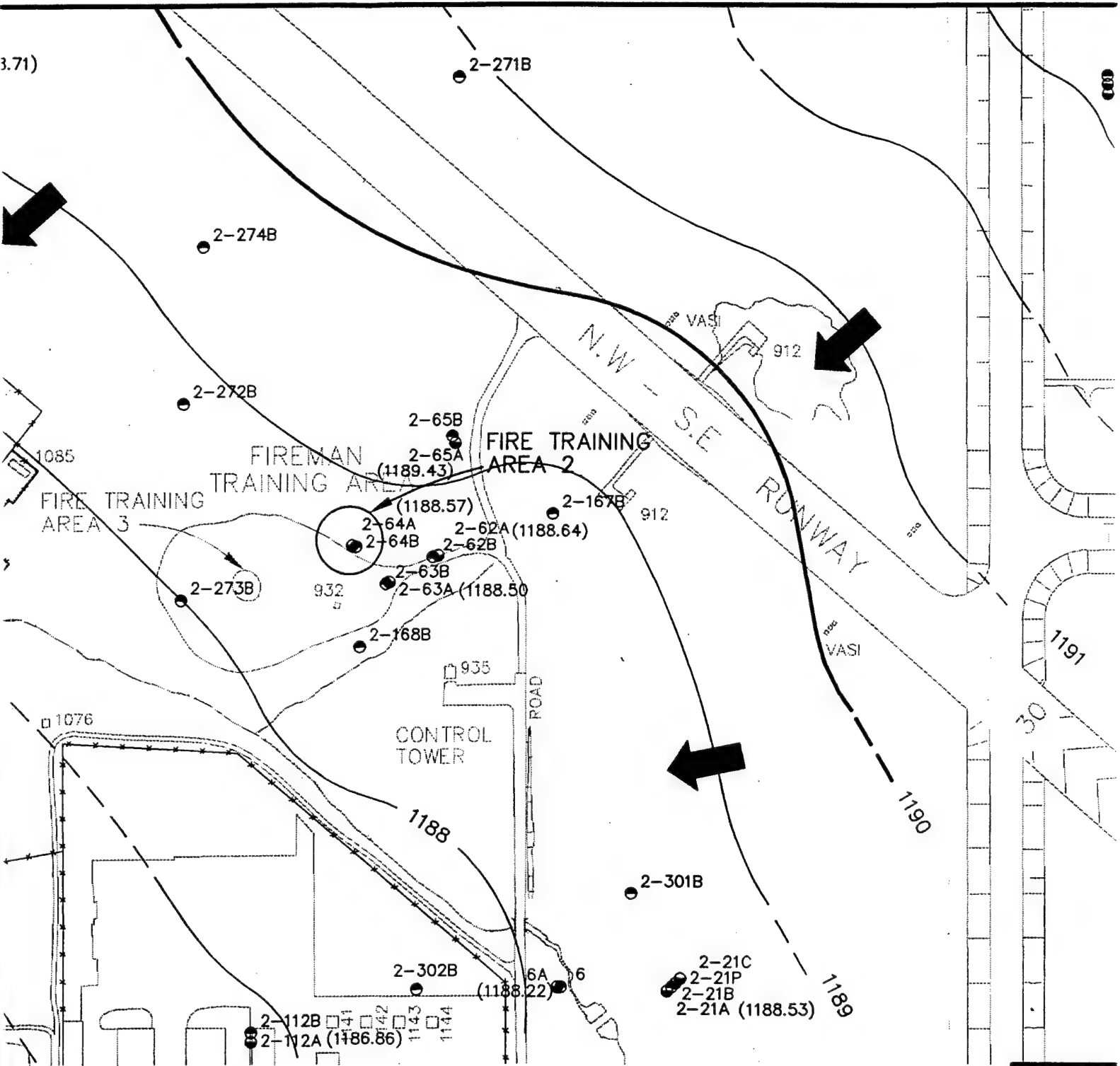
The hydrogeology at Area A also closely matches regional conditions. The USZ groundwater surface is approximately 10 to 20 feet bgs within USZ sands. Groundwater in the USZ generally is under unconfined conditions, but may be locally confined immediately beneath the Area A service station where the USZ potentiometric surface lies within intra-USZ clays. Groundwater elevations and monitoring well



LEGEND

- 
 2-142B UPPER SATURATED ZONE MONITORING WELL
LOCATION AND ID NUMBER
- 
 2-142A LOWER SATURATED ZONE MONITORING WELL
LOCATION AND ID NUMBER
- 
 DIRECTION OF GROUNDWATER FLOW
- 
 1188 LINE OF EQUAL GROUNDWATER
ELEVATION (FEET MSL),
DASHED WHERE INFERRED

①



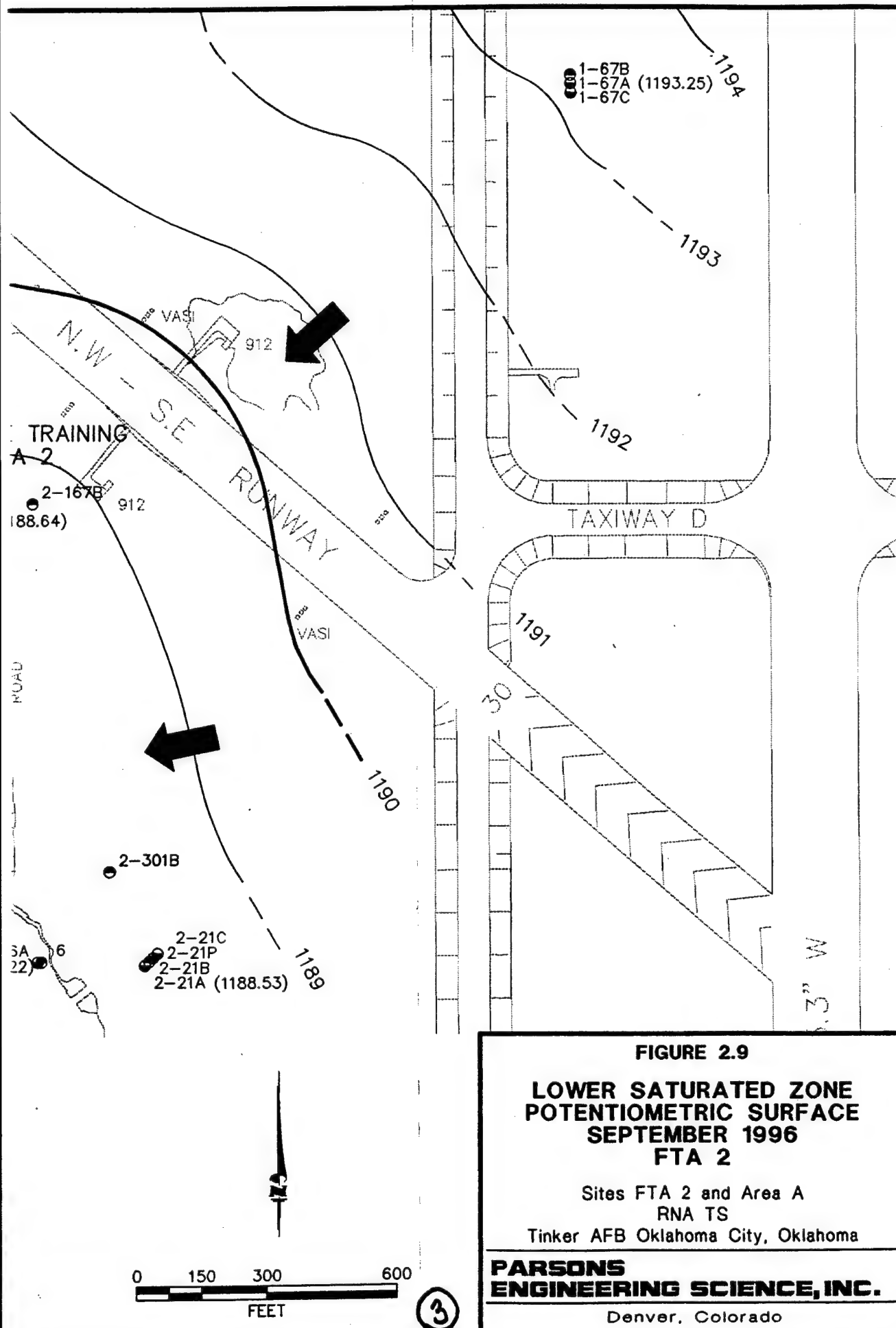
2

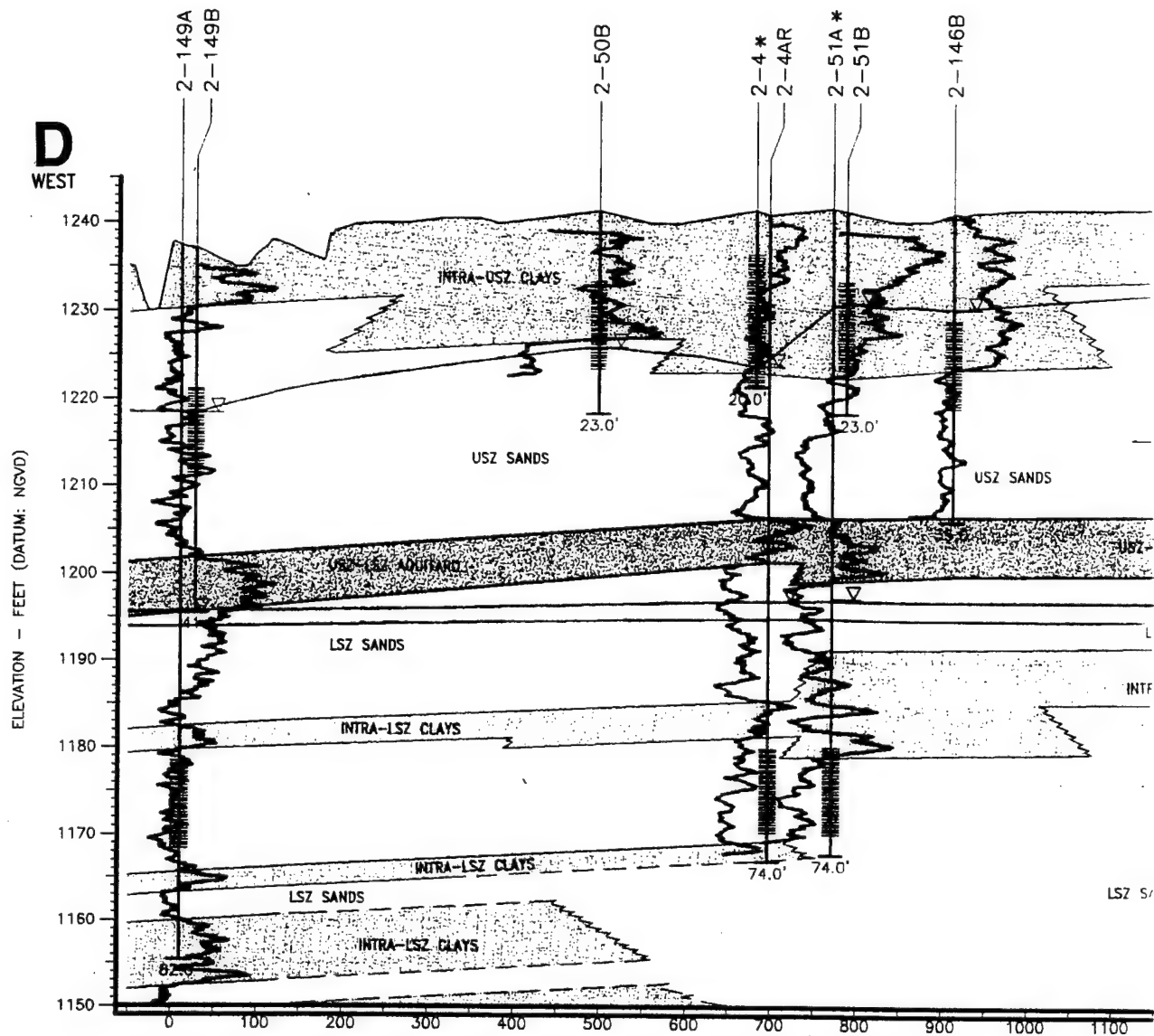


LOW
POTE

Tinker

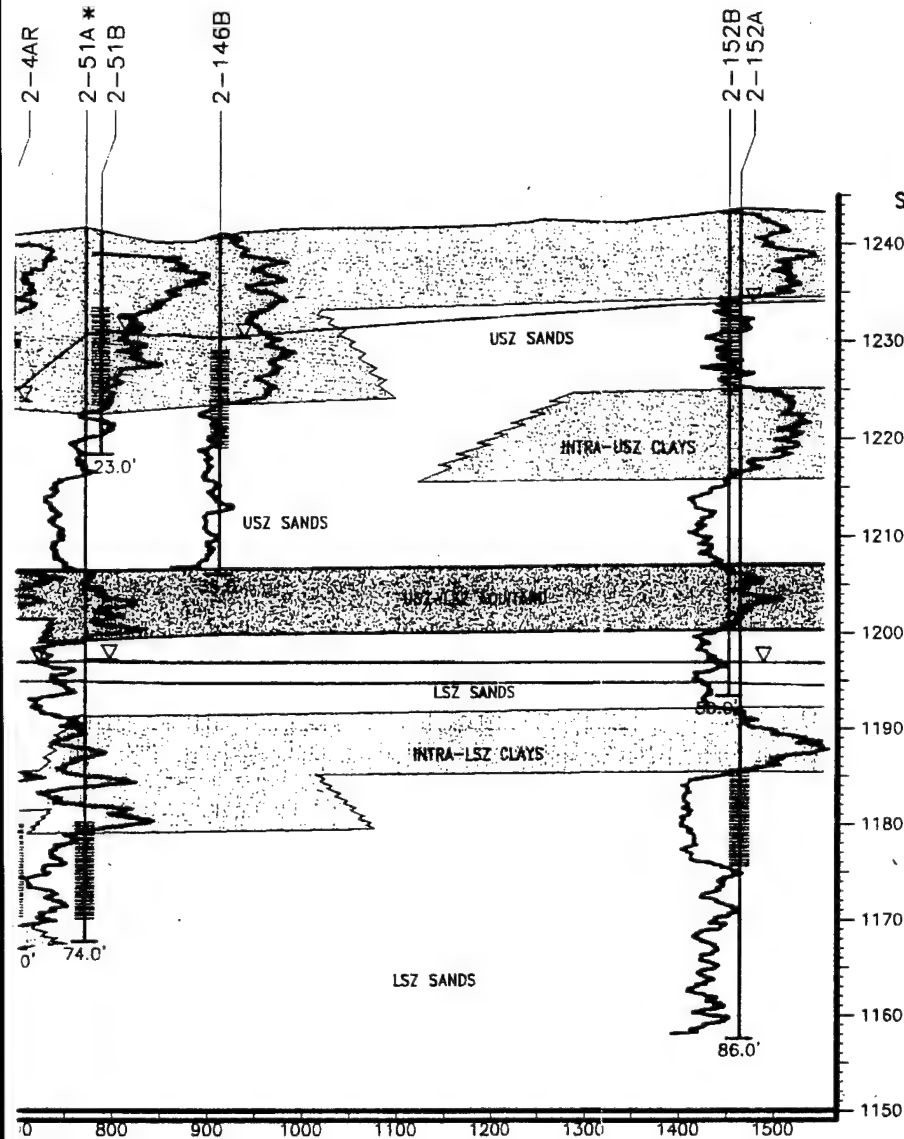
**PARSO
ENGINE**





NOTE:

- ABBREVIATIONS USED ON CROSS-SECTIONS;
 USZ → UPPER SATURATED ZONE
 LSZ → LOWER SATURATED ZONE
 LLSZ → LOWER-LOWER SATURATED ZONE
 PZ → PRODUCING ZONE



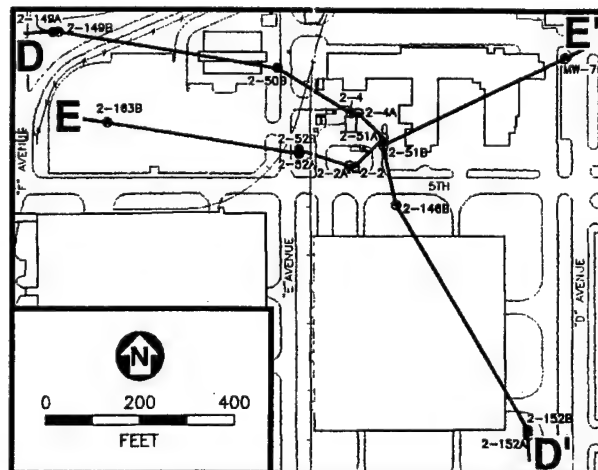
EXPLANATION

- WELL IDENTIFICATION
- WELL
- WATER LEVEL ELEVATION (JULY, 1995)
- SCREENED INTERVAL
- GAMMA LOG
- TOTAL DEPTH DRILLED
- * DIGITIZED ANALOG GAMMA LOGS
- UPPER SATURATED ZONE
- USZ POTENTIOMETRIC SURFACE
- LOWER SATURATED ZONE
- LSZ POTENTIOMETRIC SURFACE
- HYDROGEOLOGIC BOUNDARIES (DASHED WHERE INFERRED)
- LITHOLOGIC CONTACTS (DASHED WHERE INFERRED)

NOTE:
 POTENTIOMETRIC SURFACES, HYDROGEOLOGIC BOUNDARIES, AND LITHOLOGIC CONTACTS DASHED WHERE INFERRED.

GARBER-
WELLINGTON
AQUIFER

- USZ SANDS
- INTRA-USZ CLAYS
- USZ-LSZ AQUITARD
- LSZ SANDS
- INTRA-LSZ CLAYS



HY
CRC
AREA

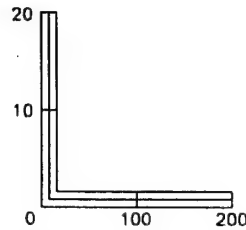
Si

T

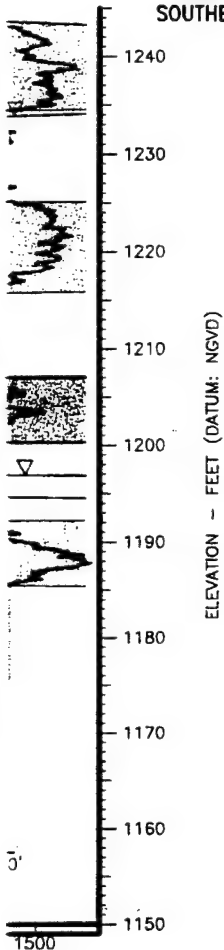
**PARSONS
ENGINEER**

NOTE:

1. ABBREVIATIONS USED ON CROSS-SECTIONS:
 USZ → UPPER SATURATED ZONE
 LSZ → LOWER SATURATED ZONE
 LLSZ → LOWER-LOWER SATURATED ZONE
 PZ → PRODUCING ZONE



D'
SOUTHEAST



EXPLANATION

- WELL IDENTIFICATION
- WELL
- WATER LEVEL ELEVATION (JULY, 1995)
- SCREENED INTERVAL
- GAMMA LOG
- 45.0' TOTAL DEPTH DRILLED
- * DIGITIZED ANALOG GAMMA LOGS
- UPPER SATURATED ZONE
- USZ POTENTIOMETRIC SURFACE
- LOWER SATURATED ZONE
- LSZ POTENTIOMETRIC SURFACE
- HYDROGEOLOGIC BOUNDARIES (DASHED WHERE INFERRED)
- LITHOLOGIC CONTACTS (DASHED WHERE INFERRED)

NOTE:
 POTENTIOMETRIC SURFACES, HYDROGEOLOGIC BOUNDARIES, AND LITHOLOGIC CONTACTS DASHED WHERE INFERRED.

- USZ SANDS
- INTRA-USZ CLAYS
- USZ-LSZ AQUITARD
- LSZ SANDS
- INTRA-LSZ CLAYS

GARBER-WELLINGTON AQUIFER

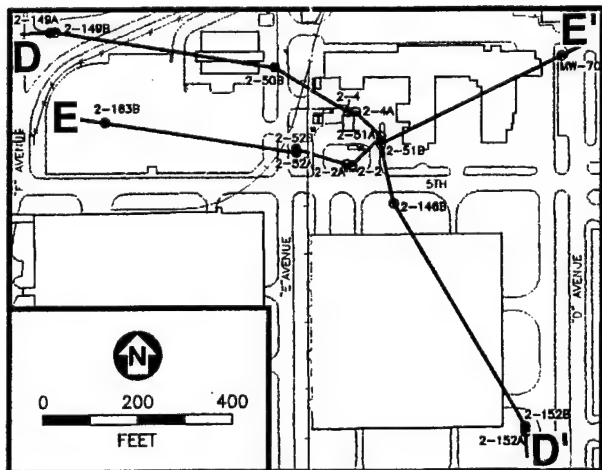


FIGURE 2.10
HYDROGEOLOGIC
CROSS-SECTION D-D'
AREA A SERVICE STATION

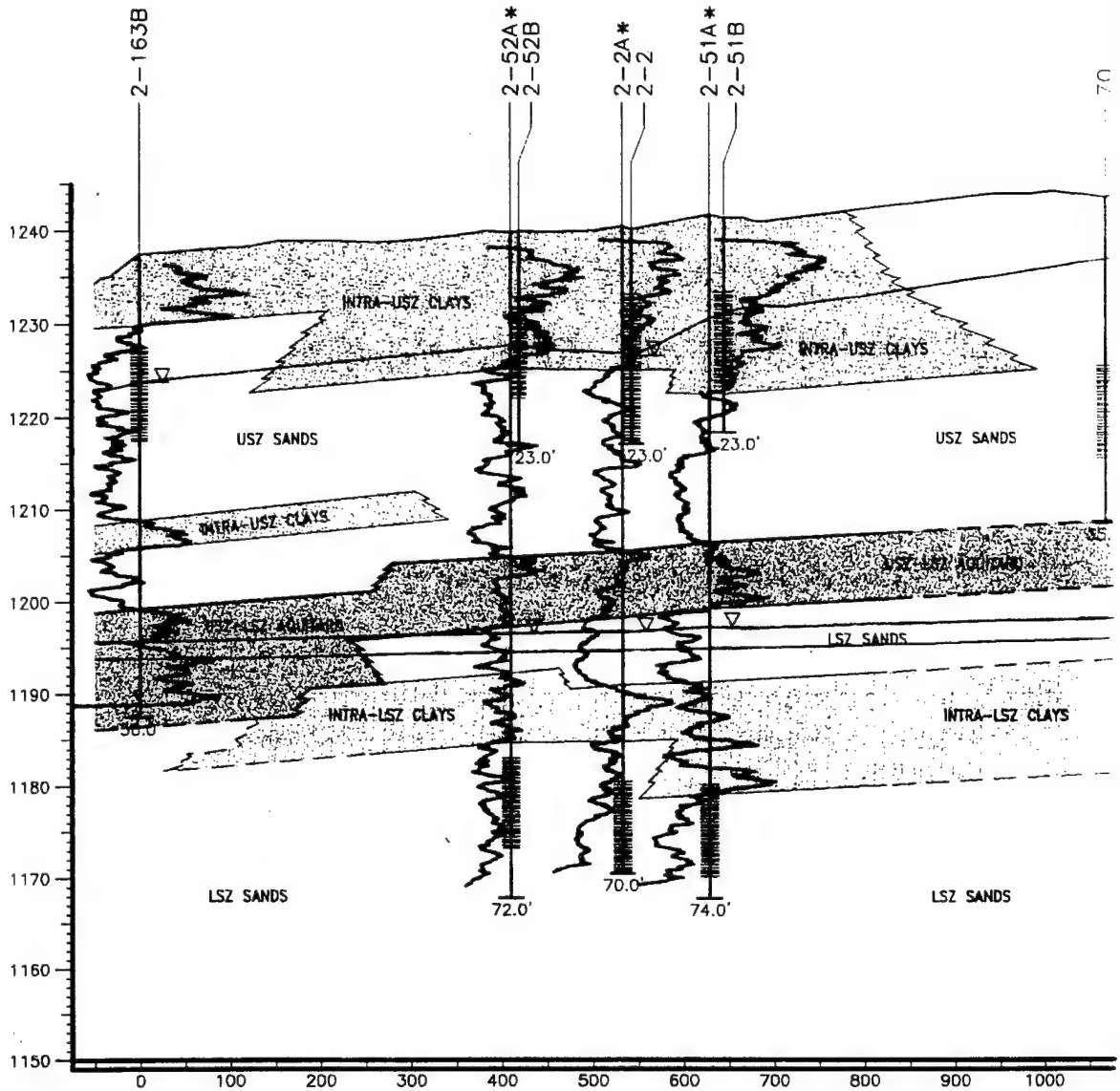
Sites FTA 2 and Area A
 RNA TS
 Tinker AFB, Oklahoma

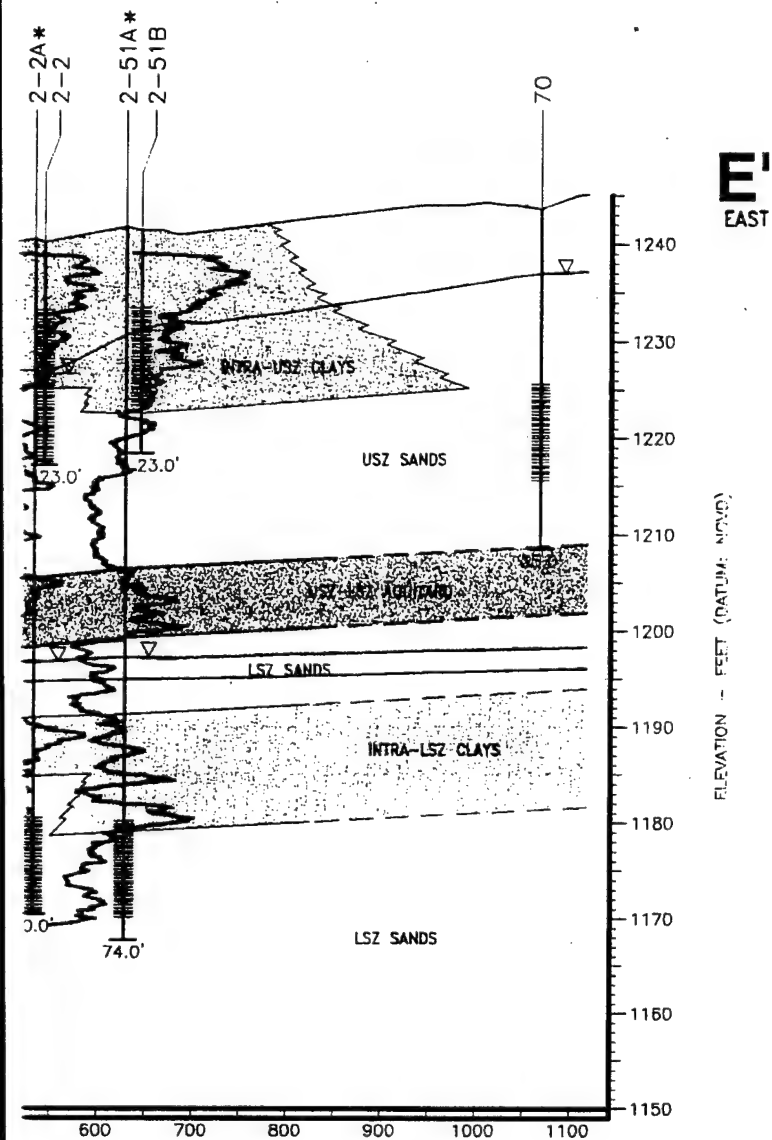
PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

E
WEST

ELEVATION - FEET (DATUM: NGVD)





NOTE:

1. ABBREVIATIONS USED ON CROSS-SECTIONS:
- USZ → UPPER SATURATED ZONE
 - LSZ → LOWER SATURATED ZONE
 - LLSZ → LOWER-LOWER SATURATED ZONE
 - PZ → PRODUCING ZONE

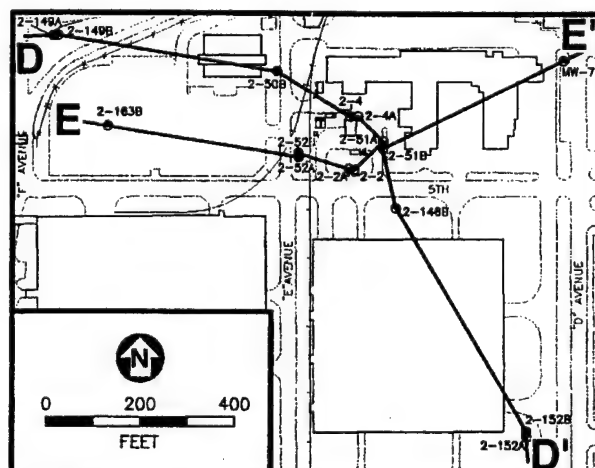
EXPLANATION

- WELL IDENTIFICATION
- WELL
- WATER LEVEL ELEVATION (JULY, 1995)
- SCREENED INTERVAL
- GAMMA LOG
- 45.0'
- TOTAL DEPTH DRILLED
- * DIGITIZED ANALOG GAMMA LOGS
- UPPER SATURATED ZONE
- USZ POTENTIOMETRIC SURF.
- LOWER SATURATED ZONE
- LSZ POTENTIOMETRIC SURF.
- HYDROGEOLOGIC BOUNDARY (DASHED WHERE INFERRED)
- LITHOLOGIC CONTACTS (DASHED WHERE INFERRED)

NOTE:

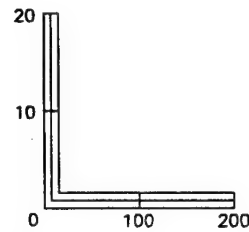
POTENTIOMETRIC SURFACES, HYDROGEOLOGIC BOUNDARIES, AND LITHOLOGIC CONTACTS DASHED WHERE INFERRED.

- GARBER-WELLINGTON AQUIFER
- USZ SANDS
 - INTRA-USZ CLAYS
 - USZ-LSZ AQUITARD
 - LSZ SANDS
 - INTRA-LSZ CLAYS



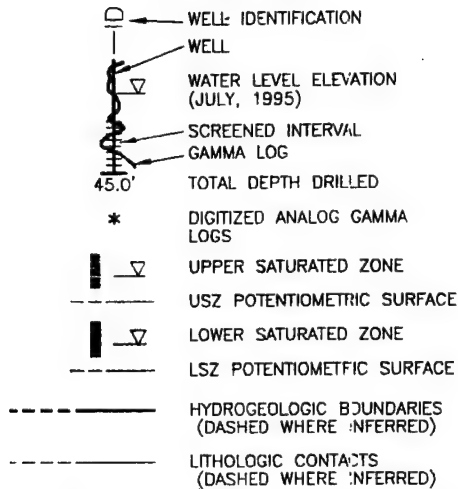
NOTE:

1. ABBREVIATIONS USED ON CROSS-SECTIONS:
- USZ —> UPPER SATURATED ZONE
 - LSZ —> LOWER SATURATED ZONE
 - LLSZ —> LOWER-LOWER SATURATED ZONE
 - PZ —> PRODUCING ZONE



SCALE IN FEET
VERTICAL EXAGGERATION = 10X

EXPLANATION



NOTE:
POTENTIOMETRIC SURFACES, HYDROGEOLOGIC BOUNDARIES, AND LITHOLOGIC CONTACTS DASHED WHERE INFERRED.

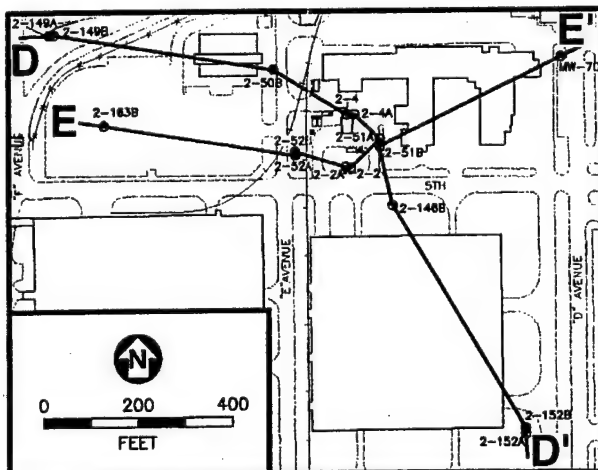
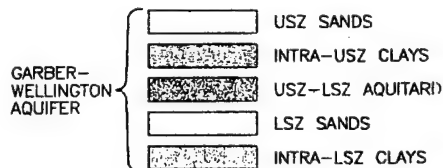


FIGURE 2.11
HYDROGEOLOGIC
CROSS-SECTION E-E'
AREA A SERVICE STATION

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

completion data are listed in Table 2.3. Figure 2.12 is a groundwater elevation contour map for the USZ based on data from September 1996 (Tinker AFB 1996 database). Flow direction in the immediate vicinity of Area A is generally northwest to southwest, and predominantly west beneath the Area A service station. A local area of low groundwater elevations is present immediately beneath the Area A service station, coinciding with a three-well product recovery system. Other local variations in USZ flow direction may be due to lithologic, topographic, or surface features. The groundwater gradient in the USZ is approximately 0.007 to 0.025 ft/ft. The flow direction and gradient in the USZ are consistent with groundwater flow direction and gradient data observed in July 1995 (IT, 1996). Hydraulic conductivity averages 1.4 feet per day (ft/day), as measured in three USZ monitoring wells by IT (1996). The base of the USZ is a layer of hard siltstone traceable across the area at a depth of approximately 35 feet bgs.

Groundwater in the LSZ is present approximately 2 to 4 feet beneath the base of the USZ-LSZ aquitard at a depth of approximately 45 feet bgs, indicating unconfined conditions (Figure 2.10). To the west of Area A the LSZ may be confined where the USZ-LSZ aquitard dips beneath the LSZ potentiometric surface (Figure 2.11). Figure 2.13 is a groundwater elevation contour map for the LSZ based on data from September 1996 (Tinker AFB 1996 database). Groundwater flow in the LSZ is towards the west and southwest at an approximate gradient of 0.003 ft/ft. Hydraulic conductivity averages 1.6 feet per day (ft/day), as measured in four LSZ monitoring wells by IT (1996). The flow direction and gradient in the USZ are consistent with groundwater flow direction and gradient data observed in July 1995 (IT, 1996).

Available geological boring logs, monitoring well completion records, and slug test data for Area A are included in Appendix C.

TABLE 2.3
MONITORING WELL SUMMARY AND
SEPTEMBER 1996 GROUNDWATER ELEVATIONS, AREA A
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

Well/Borehole Identification	Site Code	Aquifer Zone	Completion Date	Well Diameter (Inches)	Screened Interval (Feet bgs) ^{a/}	Elevation Datum (Feet msl) ^{b/}	Ground Surface Elevation	Survey Northing (State Plane)	Survey Easting (State Plane)	Depth to Water Sept. 1996 (ft bioc) ^{c/}	Depth Product (ft bioc) Sept. 96	Elevation of Water Table - Sept. 1996 ^{d/} (Feet msl)
Monitoring Wells - Upper Saturated Zone												
2-2	ST33	USZ	5/20/91	4.0	7-23	1241.99	1240.181	158257.415	2180366.34	12.02	-- ^{e/}	1229.90
2-3	ST33	USZ	5/23/91	4.0	9.5-24.5	1242.34	1240.96	158378.687	2180180.29	14.22	--	1228.05
2-4	ST33	USZ	5/20/91	4.0	5-20	1243.16	1241.49	158368.054	2180358.922	13.61	12.64	1230.33
2-50B	ST33	USZ	10/26/93	2.0	8.0-17.85	1241.30	1241.38	158461.79	2180201.11	14.40	13.69	1227.47
2-51B	ST33	USZ	10/21/93	2.0	8.0-17.85	1241.29	1241.45	158301.11	2180427.53	7.43	--	1233.86
2-52B	ST33	USZ	10/25/93	2.0	8.1-17.85	1241.81	1239.95	158292.47	2180247.69	12.62	--	1229.19
2-163B	ST33	USZ	6/1/95	4.0	10-20	1237.10	1237.50	158347.12	2179842.46	13.54	--	1223.49
2-164B	ST33	USZ	6/2/95	4.0	15-25	1239.90	1236.22	158168.82	2179771.82	14.40	--	1225.43
2-165B	ST33	USZ	6/7/95	4.0	9-19	1223.60	1224.15	158763.17	2179903.68	4.72	--	1218.81
2-166B	ST33	USZ	6/7/95	4.0	13-23	1244.97	1242.38	158641.13	2180207.24	18.16	--	1226.74
2-173B	ST33	USZ	6/14/95	4.0	12-22	1240.41	1237.94	158062.21	2180186.91	13.27	--	1227.07
2-264B	ST33	USZ	6/12/96	4.0	19-29	1234.86	1235.08	158467.86	2179427.90	15.55	--	1219.31
2-265B	ST33	USZ	6/12/96	4.0	20-30	1236.63	1234.13	158291.51	2179373.38	15.83	--	1220.80
70	PRM	USZ	10/29/87	4.0	17.8-28.4	1246.23	1243.576	158485.40	2180809.30	9.30	--	1236.86
2-146B	PRM	USZ	6/13/95	4.0	12-22	1240.70	1241.16	158179.06	2180454.43	10.28	--	1230.35
2-148B	PRM	USZ	5/20/95	4.0	15-25	1250.12	1247.46	NA ^{f/}	NA	8.71	--	1241.34
2-149B	PRM	USZ	6/7/95	4.0	16-26	1236.55	1237.08	158535.20	2179737.35	18.28	--	1218.20
2-150B	PRM	USZ	5/10/95	4.0	27-37	1234.03	1231.40	NA	NA	NA	--	NA
2-145B	BW	USZ	6/14/95	4.0	11-21	1242.75	1243.28	158576.19	2180541.42	NR	--	NR
2-152B	BW	USZ	5/18/95	4.0	9-19	1246.06	1243.46	NA	NA	13.05	--	1232.94
Monitoring Wells - Lower Saturated Zone												
2-2A	ST33	LSZ	11/24/93	2.0	60.0-70.0	1242.96	1240.51	158259.23	2180356.15	47.06	--	1195.90
2-4A	ST33	LSZ	12/29/93	2.0	61.0-70.0	1240.81	1240.98	158368.78	2180374.66	NR	--	NR
2-51A	ST33	LSZ	12/27/93	2.0	61.6-71.6	1241.65	1241.77	158317.01	2180427.68	45.23	--	1196.42
2-52A	ST33	LSZ	11/10/93	2.0	56.8-66.5	1241.98	1239.83	158283.58	2180247.93	46.26	--	1195.72
2-148A	PRM	LSZ	5/11/95	4.0	65-75	1250.11	1247.45	NA	NA	50.80	--	1199.24
2-149A	PRM	LSZ	6/5/95	4.0	59-69	1236.72	1237.39	158534.34	2179725.83	42.38	--	1194.27
2-152A	BW	LSZ	5/18/95	4.0	58-68	1246.36	1243.63	NA	NA	50.44	--	1195.85

a/ feet bgs indicates elevation in feet below ground surface.

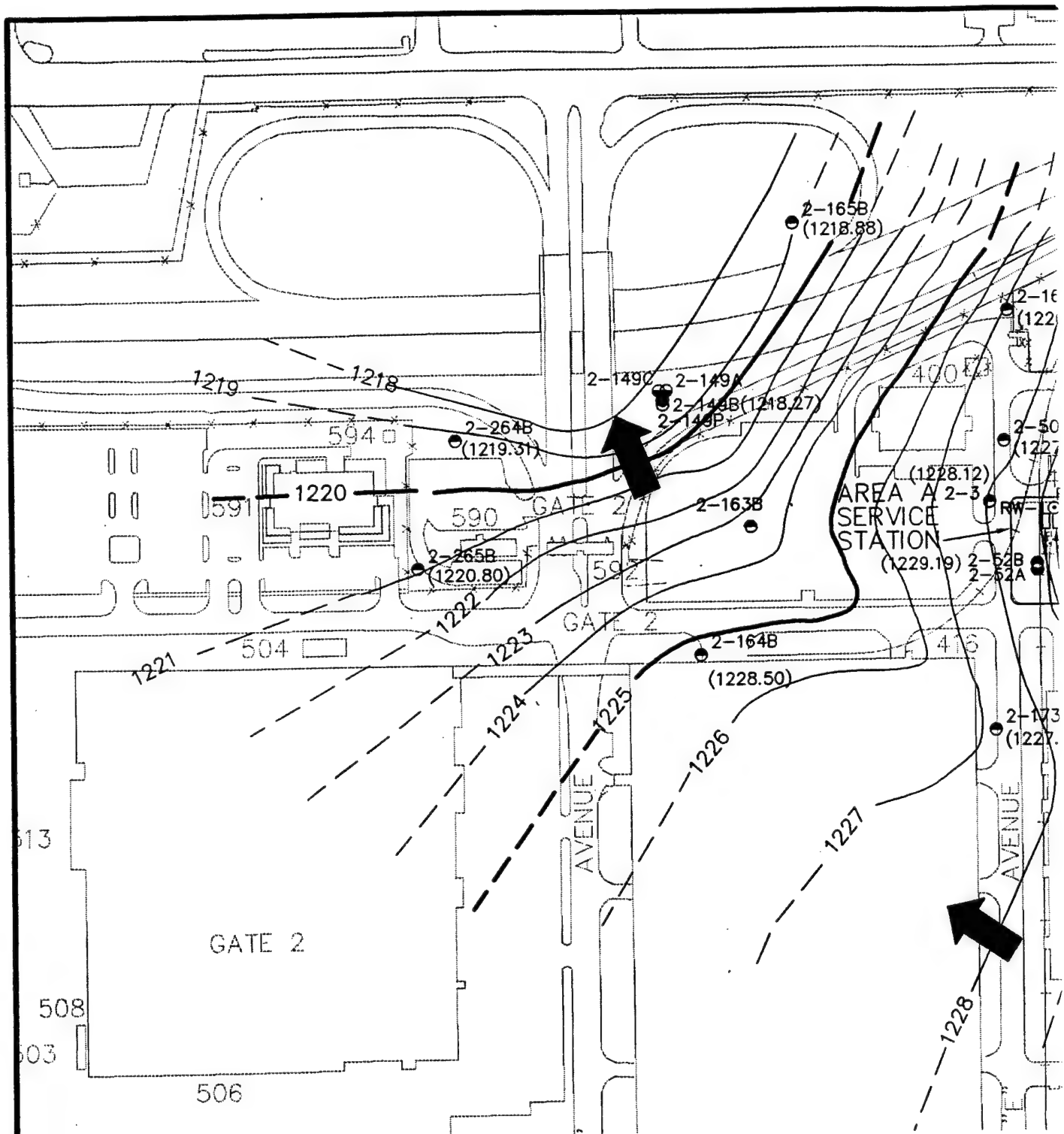
b/ feet msl indicates elevation in feet above mean sea level.

c/ bioc indicates depth measured below top of well casing.

d/ Groundwater elevation corrected for the presence of free product using a product specific gravity of 0.80.

e/ -- indicates no measurable amount of free product present.

f/ NA indicates the data are not currently available.

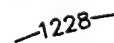


LEGEND

- 2-165B ● UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- 2-2A ● LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- RW-1 ○ PRODUCT RECOVERY WELL
- WS-32 ● WATER SUPPLY WELL

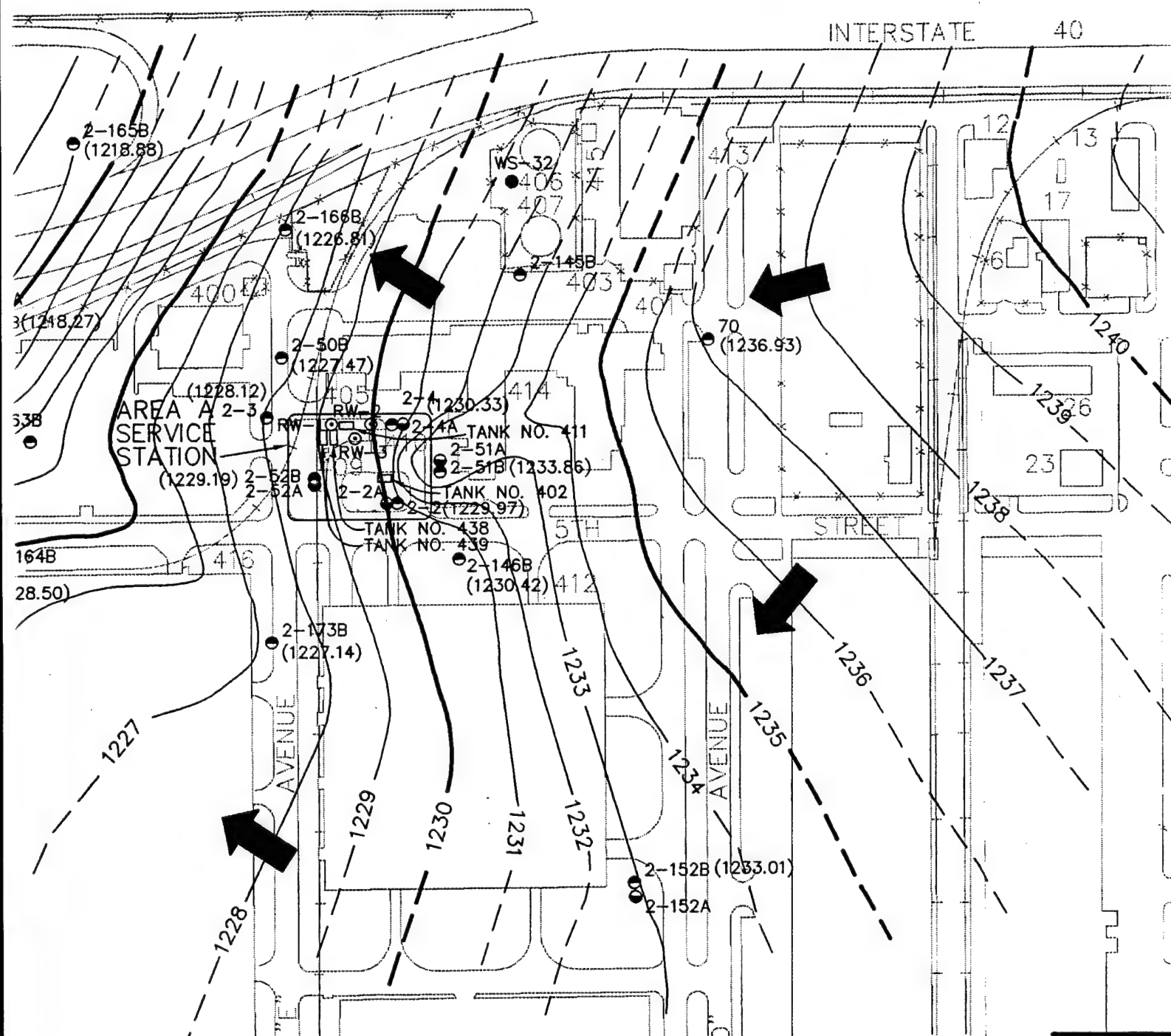


DIRECTION OF GROUNDWATER FLOW



LINE OF EQUAL GROUNDWATER ELEVATION (FEET MSL), DASHED WHERE INFERRED





DIRECTION OF GROUNDWATER FLOW

LINE OF EQUAL GROUNDWATER
ELEVATION (FEET MSL),
DASHED WHERE INFERRED

0 100 200 400
FEET

2

UPPE
POTEN
AREA

S

Si

Tinker A

PARSON
ENGINE

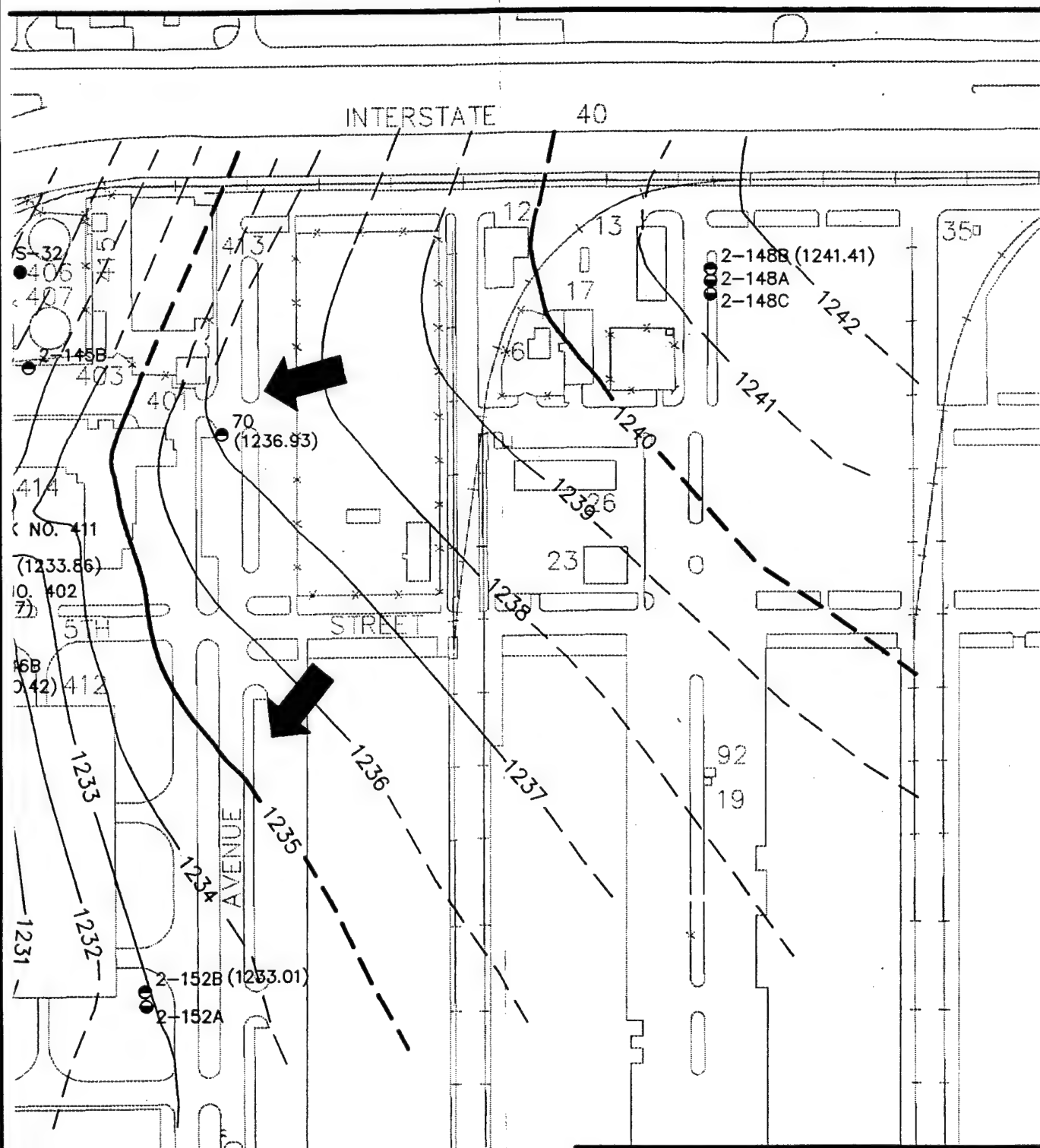


FIGURE 2.12

**UPPER SATURATED ZONE
POTENTIOMETRIC SURFACE
AREA A SERVICE STATION
SEPTEMBER 1996**

Sites FTA 2 and Area A
RNA TS

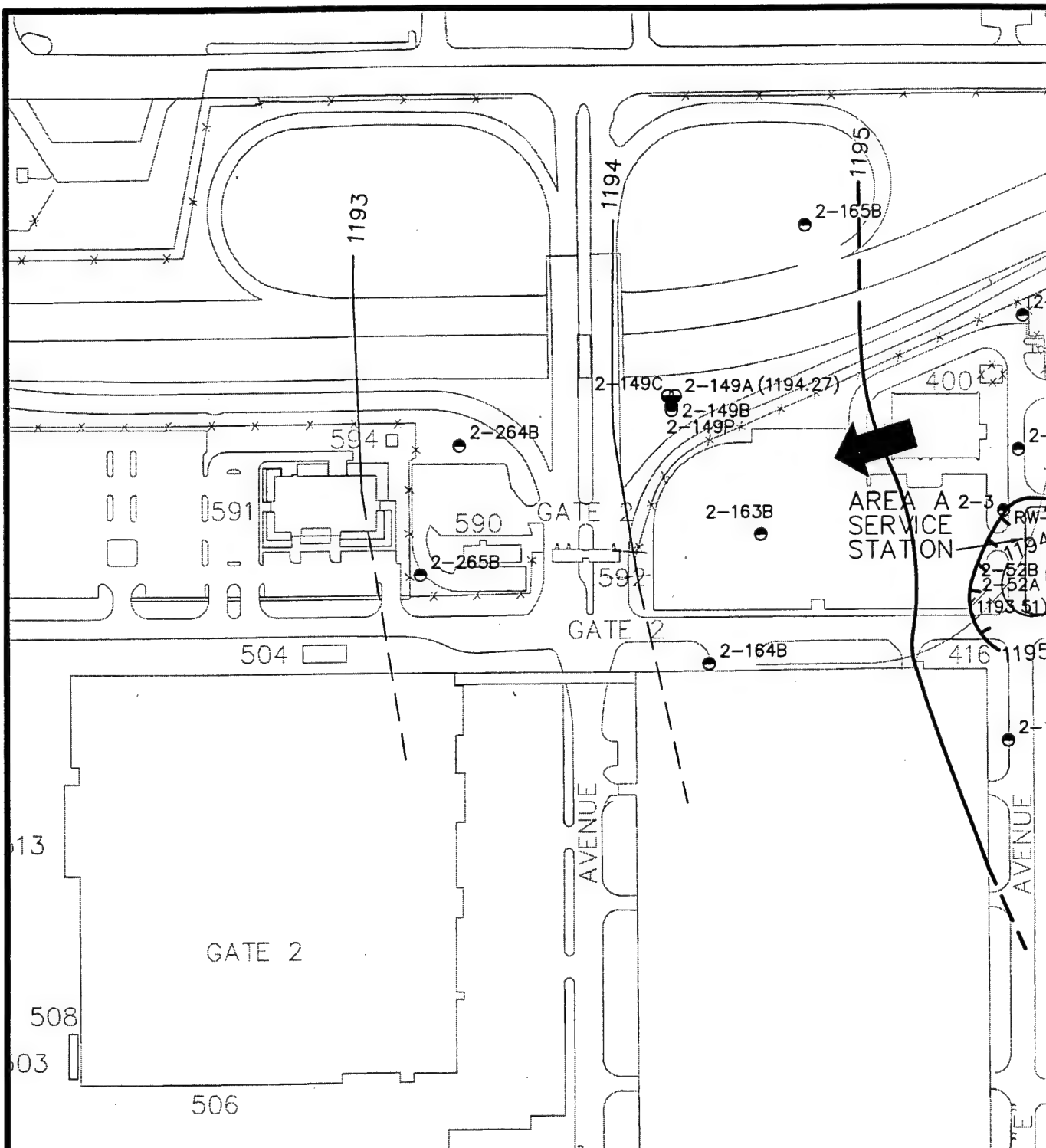
Tinker AFB Oklahoma City, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

0 100 200 400
FEET

3



LEGEND

- 2-165B ● UPPER SATURATED ZONE MONITORING WELL
LOCATION AND ID NUMBER
- 2-2A ● LOWER SATURATED ZONE MONITORING WELL
LOCATION AND ID NUMBER
- RW-1 ○ PRODUCT RECOVERY WELL
- WS-32 ● WATER SUPPLY WELL



DIRECTION OF GROUNDWATER FLOW

1185

LINE OF EQUAL GROUNDWATER
ELEVATION (FEET MSL),
DASHED WHERE INFERRED

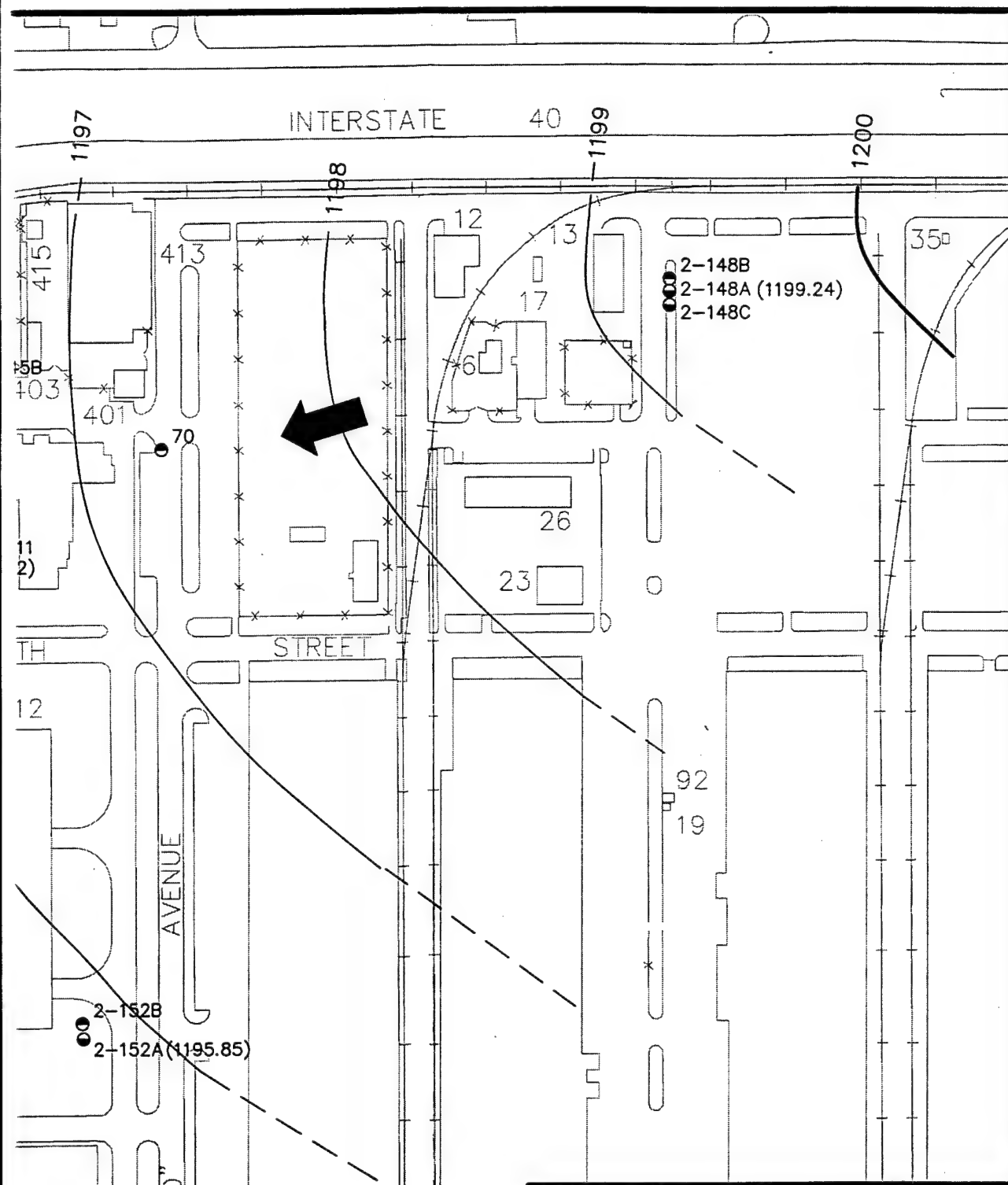


FIGURE 2.13

**LOWER SATURATED ZONE
POTENTIOMETRIC SURFACE
AREA A SERVICE STATION
SEPTEMBER 1996**

Sites FTA 2 and Area A
RNA TS

Tinker AFB Oklahoma City, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

0 100 200 400
FEET

③

2.1.3 Summary of Analytical Results for FTA 2

2.1.3.1 Soil Quality

In a 1987 soil investigation by the USACE (USACE, 1988), seven soil boreholes were drilled to a maximum depth of 7 feet and soil samples were collected and analyzed for VOCs and metals. From October to December 1993, 21 soil samples were collected from 4 locations at depths from 2 to 30 feet bgs and analyzed for VOCs, SVOCs, TPH, and metals (IT, 1994). In 1995, an additional 37 soil samples were collected from 5 soil boreholes and two monitoring well boreholes (TT, 1996). Low concentrations of TPH, VOC, and SVOC compounds were detected, including methylene chloride, 1,1,1-trichloroethane (TCA), butylbenzophthalate, di-n-butylphthalate, and bis(2-ethylhexyl)phthalate. TCA was detected at concentrations ranging from 0.07J (estimated concentration) to 6.7 micrograms per kilogram ($\mu\text{g/kg}$). Metals detected at the site were within background concentrations. The presence of TCA in the soil suggests the possible use of chlorinated solvents at this site (IT, 1994; TT, 1996). However, the low detected concentrations of TCA do not indicate that Site FTA 2 is a significant source for chlorinated solvents.

2.1.3.2 Groundwater Quality

A total of 14 monitoring wells are present at Site FTA 2 (IT, 1994), with an additional 16 monitoring wells located up- and cross-gradient from the site (Table 2.4). Groundwater samples were collected in December 1993, September to October 1995, and July 1996. Samples were analyzed for VOCs, SVOCs, metals, and general chemistry. A summary of the laboratory analytical results for VOCs in groundwater samples for 1996 is presented in Table 2.4. Summary tables of analytical data for previous sampling events are included in Appendix B. Figure 2.14 is a map of Site FTA 2 depicting monitoring well locations, with reported contamination levels for selected VOCs [tetrachloroethene (PCE), trichloroethene (TCE), *cis*-1,2-dichloroethene

TABLE 2.4
SUMMARY OF VOLATILE ORGANIC COMPOUNDS IN FTA 2 GROUNDWATER
JULY TO SEPTEMBER 1996
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

Sample Identification	Date Sampled	Units	1,2-Dichlorobenzene	1,3-Dichlorobenzene	1,4-Dichlorobenzene	1,2-Dichloroethane	Chloroform	Chlorobenzene	Methylene Chloride	Tetrachloroethene	Trichloroethene	Trichlorofluoromethane	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	Vinyl Chloride
Upper Saturated Zone															
2-62B	7/24/96	(µg/L) ^{a/}	460	9J ^{b/c/}	45 ^{d/}	190J	220J	<250	1400B	<250	4300	<250	960	<250	<250
2-63B	7/24/96	(µg/L)	<10	<10	<10	<10	<10	<10	<10	<10	22	91	190	<10	<10
2-64B	7/24/96	(µg/L)	<25	<25	<25	<25	<25	<25	37B ^{u/}	<25	470	<25	180	<25	<25
2-65B	7/24/96	(µg/L)	10	<2	5	4	<2	19	<2	44	55	<2	33	4	2
2-167B	7/24/96	(µg/L)	<1	<1	<1	<1	<1	<1	4B	<1	1	<1	<1	<1	<1
2-168B	7/24/96	(µg/L)	<5	<5	<5	<5	<5	<5	<5	<5	<5	140	19	<5	<5
2-271B	9/11/96	(µg/L)	<0.5	<0.5	<0.5	<0.8	<0.8	<0.5	11B	<0.8	<0.8	<1	<0.5	<0.8	<1
2-272B	8/22/96	(µg/L)	<0.5 ^{b/}	<0.5	<0.5	0.5J	<0.8	<0.5	0.61B	<0.8	9	<1	0.6	<0.8	<1
2-273B	8/9/96	(µg/L)	<0.5	<0.5	<0.5	<0.8	<0.8	<0.5	0.451B	<0.8	<0.8	<1	<0.5	<0.8	<1
2-274B	8/22/96	(µg/L)	<0.8	<0.8	<0.8	<0.13	<0.13	<0.8	13JB	<0.13	260	<17	46	<0.13	<17
2-301B	7/16/96	(µg/L)	<0.5	<0.5	<0.5	<0.8	<0.8	<0.5	11B	<0.8	<0.8	<1	<0.5	<0.8	<1
2-302B	8/30/96	(µg/L)	<5	<5	<5	<8	<8	<5	11JB	12	220	<10	<5	<8	<10
Lower Saturated Zone															
2-62A	7/24/96	(µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
2-63A	7/24/96	(µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
2-64A	7/24/96	(µg/L)	<1	<1	<1	<1	<1	<1	1B	<1	<1	0.8J	<1	<1	<1
2-65A	7/24/96	(µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

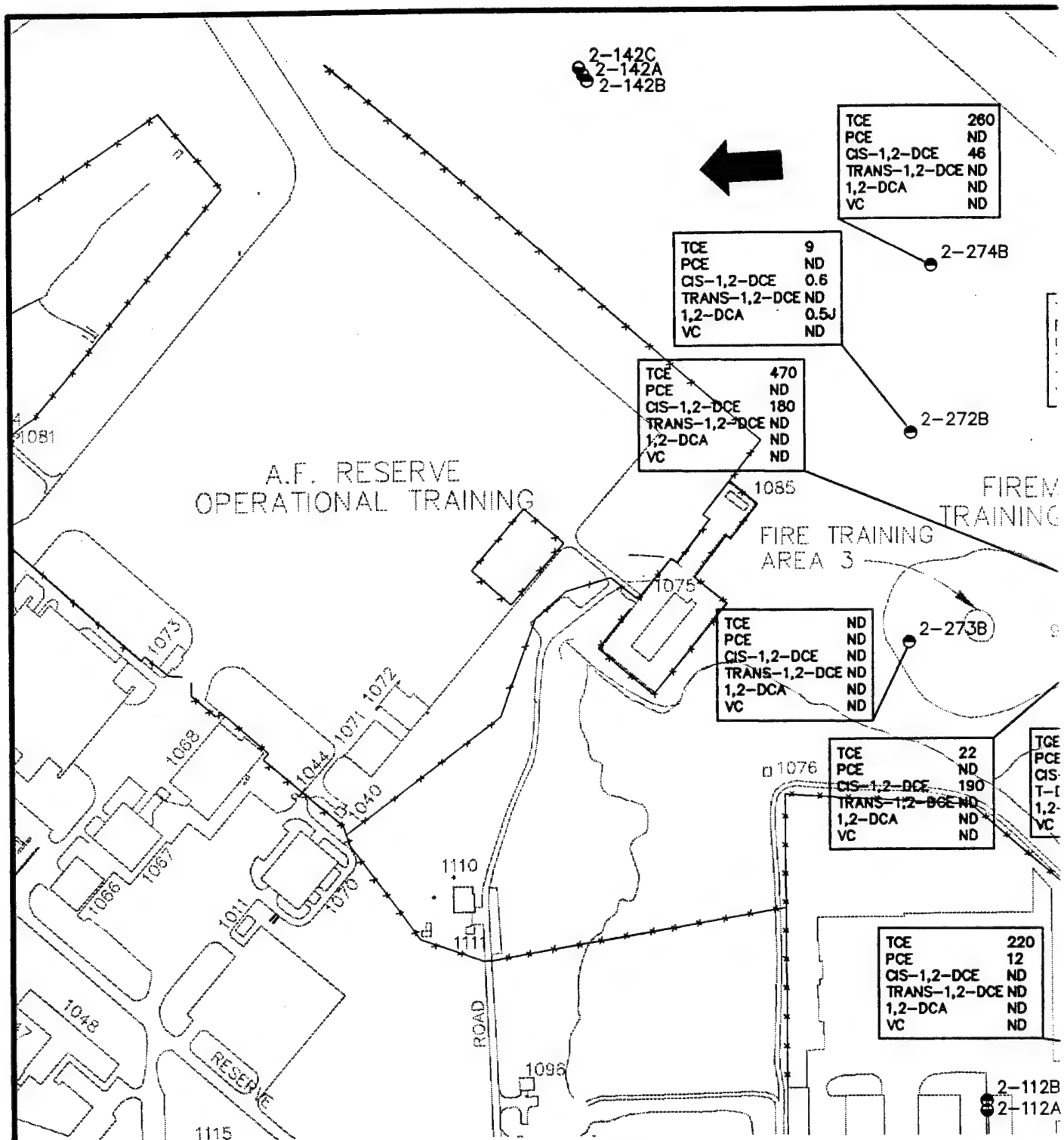
Tinker AFB, 1996

a/ µg/L indicates micrograms per liter.

b/ J flag indicates an estimated concentration detected below the project reporting limit, but above the method detection limit.

c/ Compound concentration detected in analysis for semi-volatile organic compounds.

d/ B flag indicates compound was detected in the method blank.



LEGEND

2-142B ● UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

2-142A ● LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

TCE TRICHLOROETHENE

PCE TETRACHLOROETHENE

CIS-1,2-DCE CIS-1,2-DICHLOROETHENE

TRANS-1,2-DCE TRANS-1,2-DICHLOROETHENE

1,2-DCA 1,2-DICHLOROETHANE

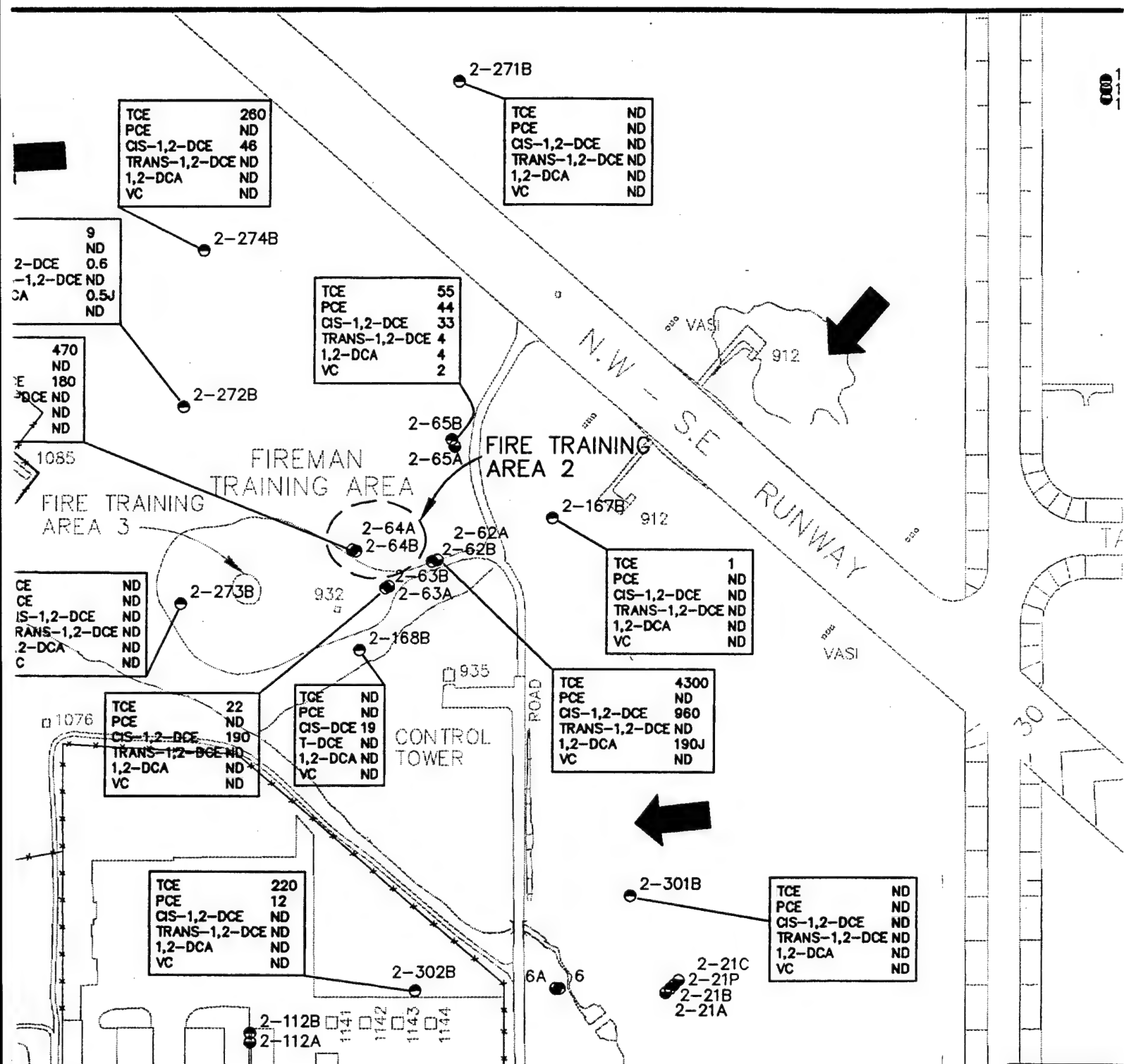
VC VINYL CHLORIDE

ND NOT DETECTED

← DIRECTION OF GROUNDWATER

ALL CONCENTRATIONS IN MICROGRAMS PER L

①



CHLORINE
HYDROGEN
IN JULY

Si

Tinker /

PARSONS ENGINEERING

0 150 300 600
FEET

2

1B

TCE	ND
PCE	ND
CIS-1,2-DCE	ND
TRANS-1,2-DCE	ND
1,2-DCA	ND
VC	ND

1-67B
1-67A
1-67C

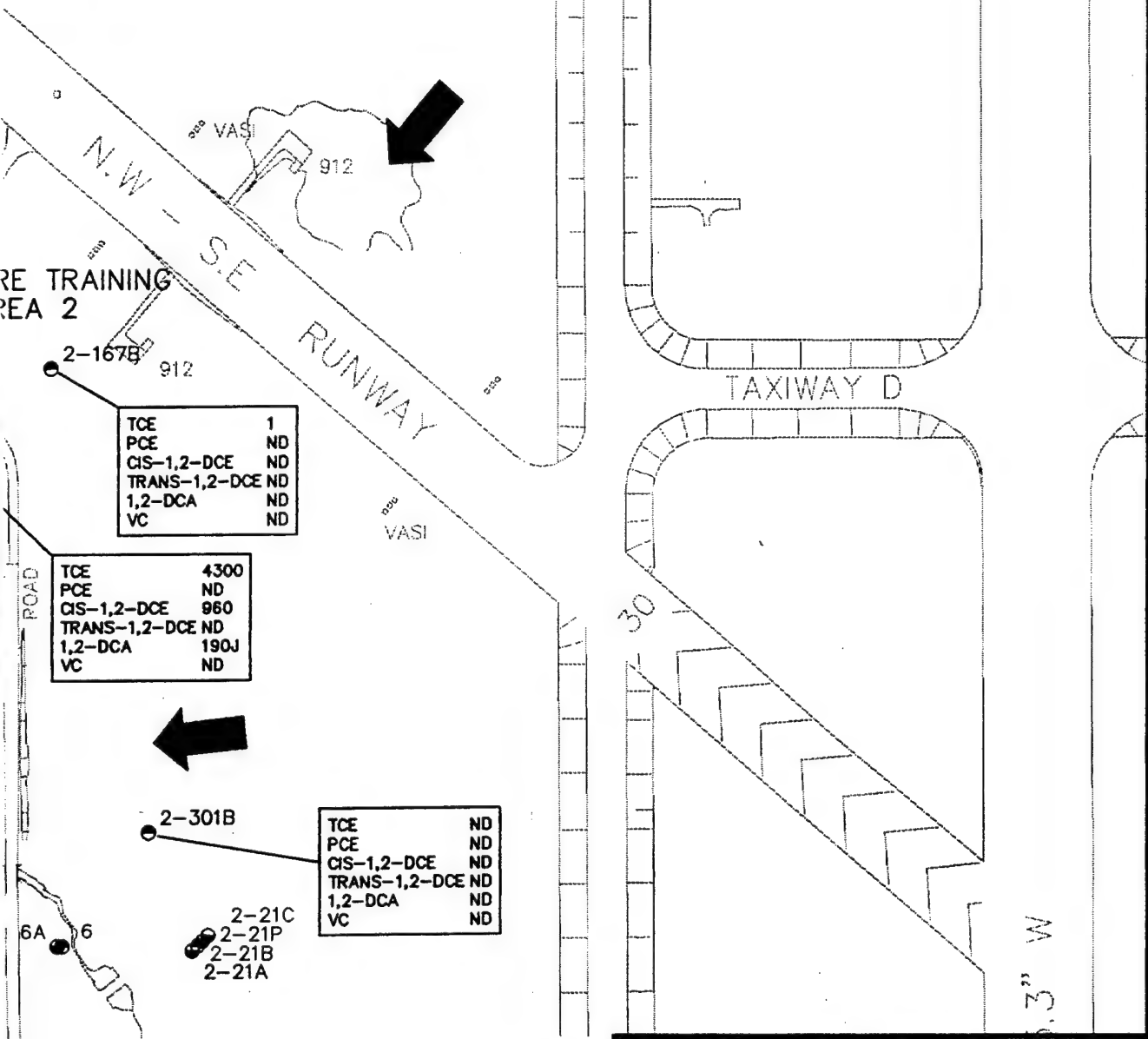


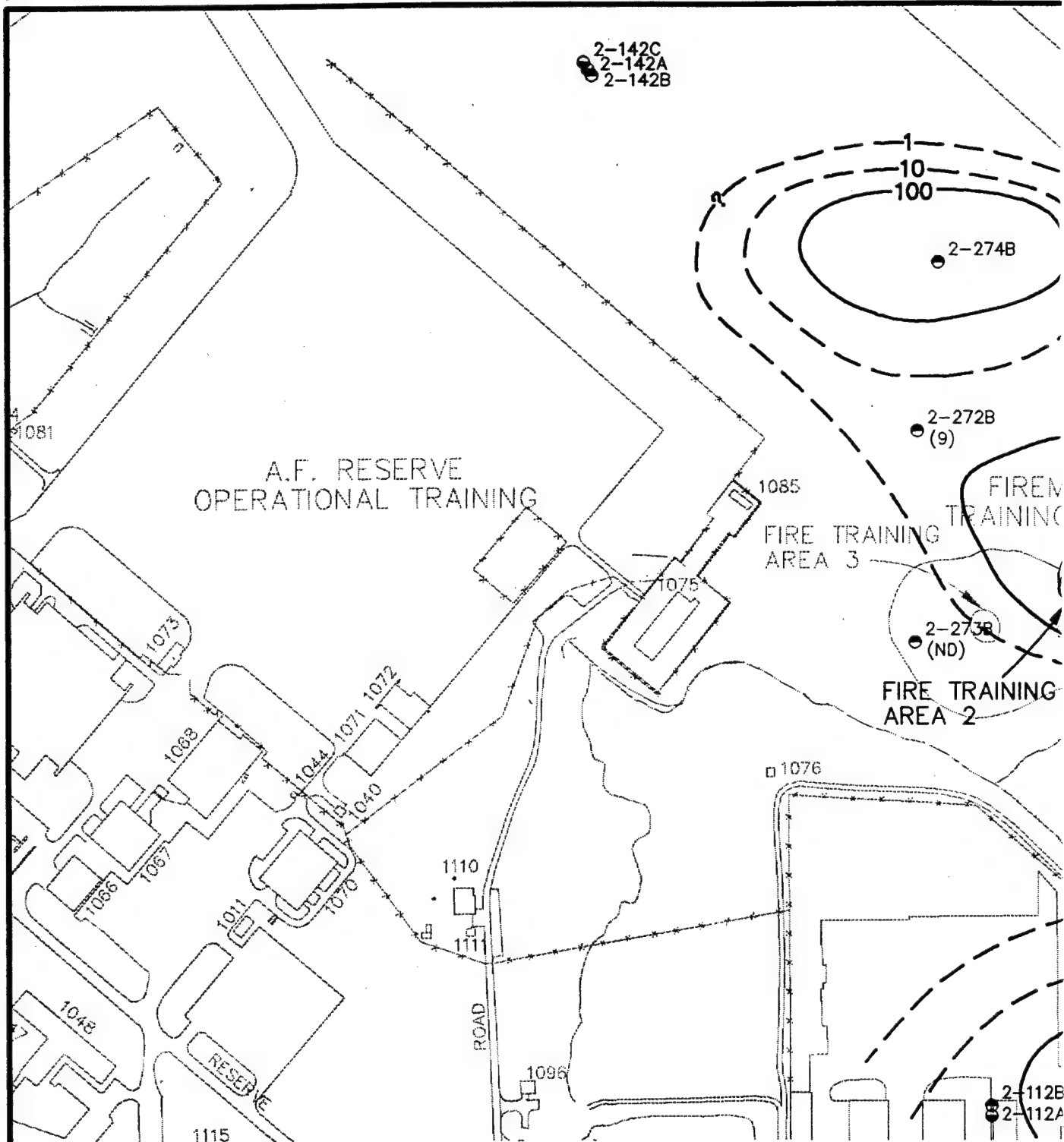
FIGURE 2.14
CHLORINATED ALIPHATIC
HYDROCARBONS DETECTED
IN USZ GROUNDWATER
JULY TO SEPTEMBER 1996
FTA 2
Sites FTA 2 and Area A
RNA TS
Tinker AFB Oklahoma City, Oklahoma

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado

(DCE), *trans*-1,2-DCE, 1,2-dichloroethane (DCA), and vinyl chloride (VC)]. Concentration contours for TCE in the USZ for the July 1996 sampling event are depicted in Figure 2.15. No VOC compounds have been detected in the LSZ, indicating that the USZ-LSZ aquitard is an effective barrier to vertical contaminant migration.

TCE was detected at a maximum concentration of 4,300 micrograms per liter ($\mu\text{g/L}$) at monitoring well 2-62B in July 1996. TCE had previously been detected in concentrations as high as 9,100 $\mu\text{g/L}$ at monitoring well 2-62B in September 1995. The TCE plume at FTA 2 is defined in the USZ by non-detections in wells 2-168B (south), 2-273B (west), 2-271B (north), and to the east by a low detected concentration of 1 $\mu\text{g/L}$ at well 2-167B. However, TCE has also been detected at locations cross-gradient from FTA 2, including well 2-274B (260 $\mu\text{g/L}$) to the north, and 2-302B (220 $\mu\text{g/L}$) to the south, indicating that more than one TCE plume may be present in the general fire training area. Other VOC compounds detected at FTA 2 include PCE and breakdown products of PCE and TCE including *cis*-1,2-DCE, *trans*-1,2-DCE, and VC, indicating that natural attenuation of PCE or TCE may be occurring at the site. No BTEX compounds were detected in groundwater samples from the USZ in July 1996.

Only BTEX compounds and organic solvents are included as part of this RNA demonstration; therefore, results for other potential contaminants such as herbicides, polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, or metals are not summarized in this work plan. These compounds have been addressed in previous reports. For information on these compounds the reader is referred to IT, 1994.



LEGEND

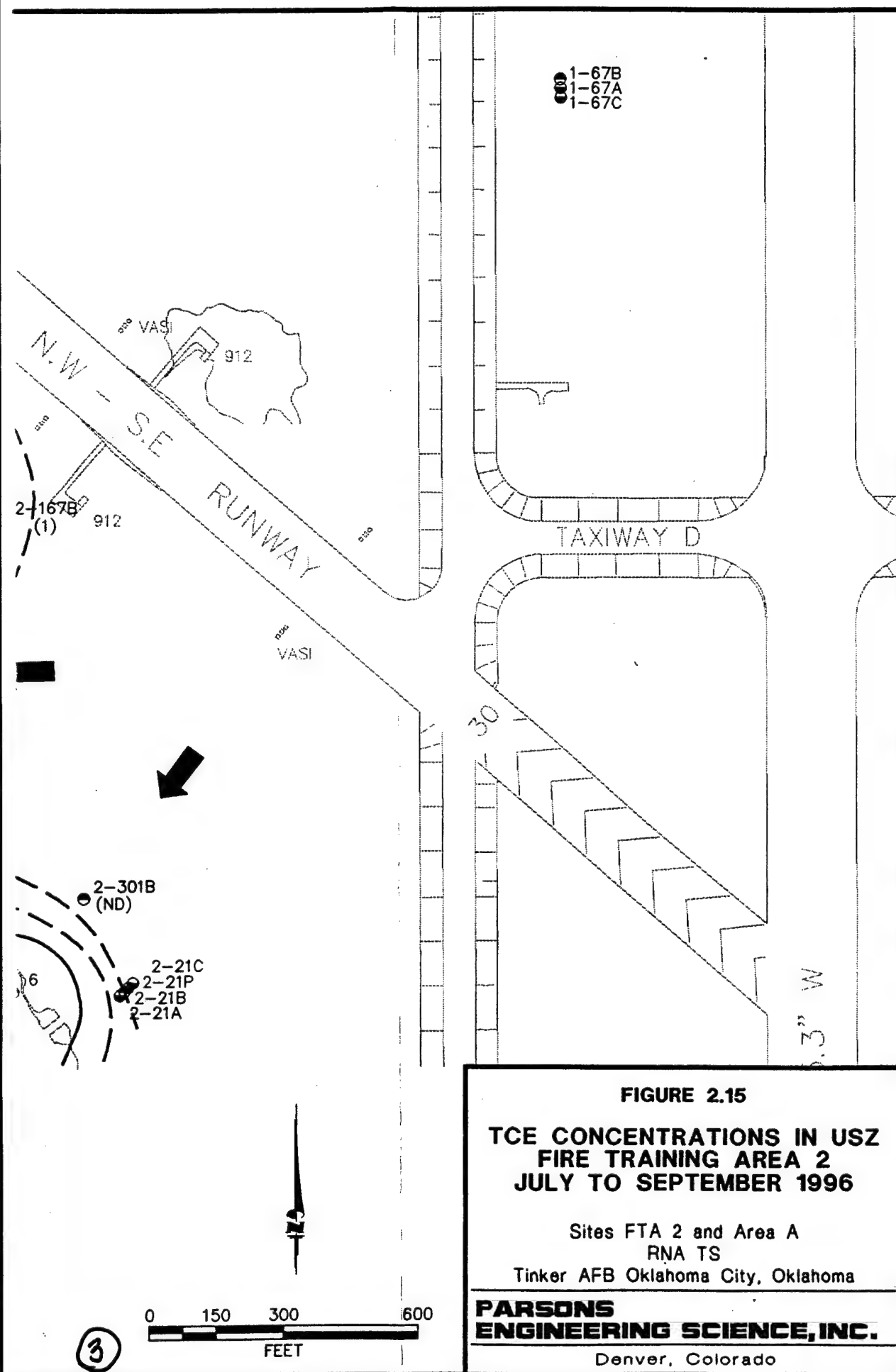
2-142B (4300) ● UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER [CONCENTRATION OF TCE IN MICROGRAMS PER LITER (µg/L)]

2-142A ● LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

ND NOT DETECTED

➔ DIRECTION OF GROUNDWATER FLOW

—60— LINE OF EQUAL TCE CONCENTRATION (µg/L), DASHED WHERE INFERRED



2.1.4 Summary of Analytical Results for Site Area A

2.1.4.1 Soil Quality

Soil samples collected and analyzed from Site Area A include 11 samples from five soil boreholes drilled in 1990 by ERI and 50 samples from eight soil boreholes drilled by WSCI in 1991. These samples were analyzed for BTEX, TPH, and total lead. An additional 35 samples from ten soil boreholes were collected by IT from October 1993 to January 1994, and analyzed for VOCs (including BTEX), SVOCs, and metals. All soil samples were collected from the USZ stratigraphic interval. Analytical summary tables for soil sampling results at Area A are included in Appendix C.

Analytical results indicate that the highest concentrations of BTEX were encountered in soil samples from boreholes located within 20 to 40 feet of existing USTs. Mobile light non-aqueous phase liquid (LNAPL) was also detected at the Area A service station. The proximity to existing USTs suggests that residual soil BTEX contamination and mobile LNAPL originated from leaking USTs at Area A. Figure 2.16 shows soil borehole locations and the distribution of total BTEX in soil at the Area A Service Station.

Only low concentrations of other VOC compounds, including 1,2-DCA, 2-butanone, acetone, chlorobenzene, methylene chloride, TCE, and *cis*-1,2-DCE, have been detected in Area A soil samples. Chlorinated solvents (TCE and *cis*-1,2-DCE) were only detected in a single soil sample at a depth of 20 to 21 feet bgs in soil borehole SB-006, located to the north of the area of soil impacted by BTEX contamination. This CAH detection is may not be sufficient to account for the concentrations of dissolved CAH compounds present in Area A groundwater, as discussed in the following section. To date a CAH source has not been identified at Area A.

BLDG
417

2-50B
1,550(9-10')

SB-006
<8(9-10')

2-3(SB-8)
<8(9')

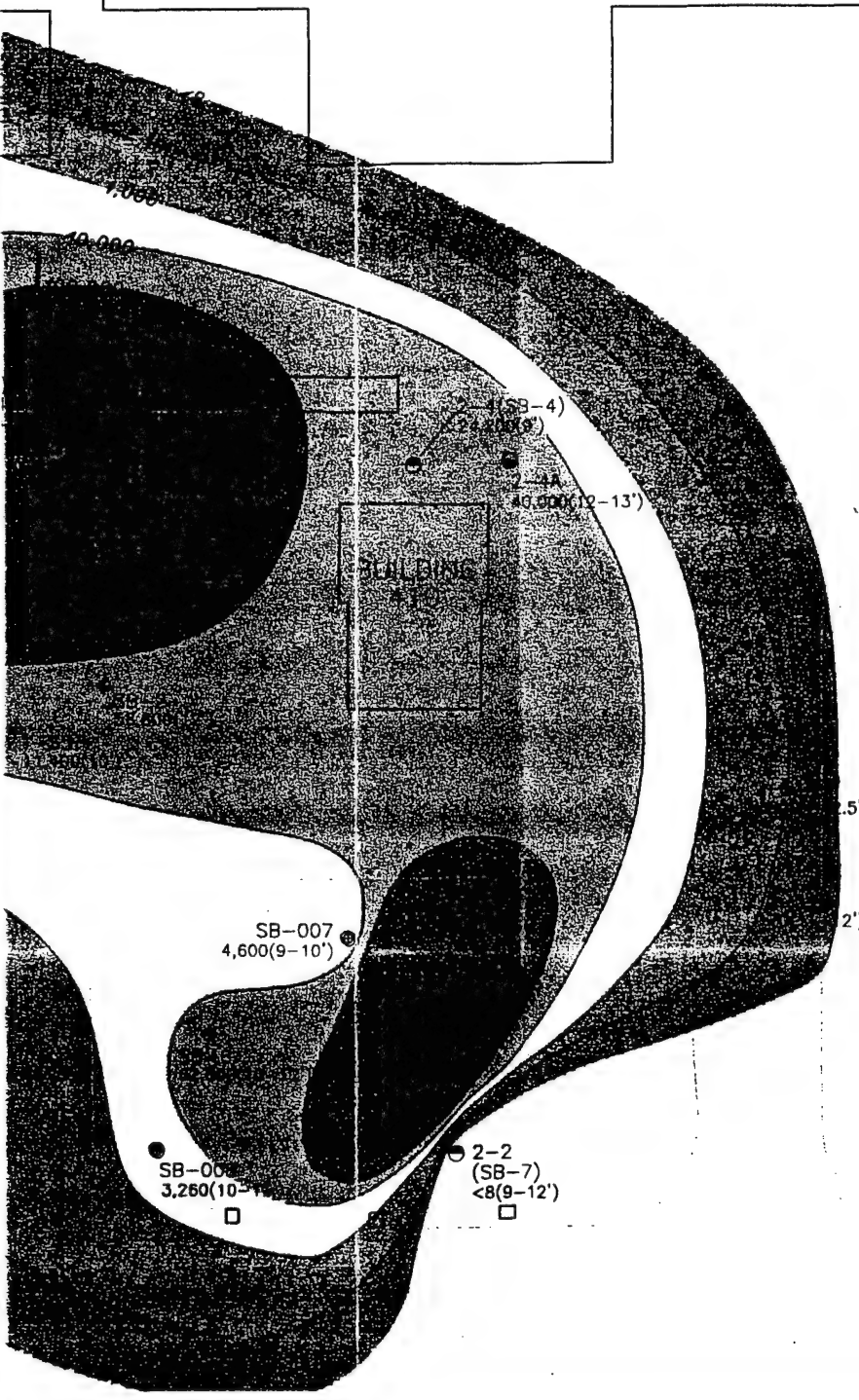
3,270(7-9")
SB-5

SB-007
4,600(9-10')

SB-008
3,260(10-11')

BUILDING 414












- RW-2 (S)
- 2-51B (U)
- 2-51A (L)
- SB-6 (S)
- 1-S2 (S)
- SB-008 (S)
- #402 (L)
- 100 (C)
- 4,600(9") (T)
- 4,600(9") (C)
- 4,600(9") (C)
- 4,600(9") (C)
- 4,600(9") (C)
- 4,600(9") (C)



TOTAL
IN S
AF

PARSC
ENGINE

LEGEND

- RW-2  RECOVERY WELL LOCATION AND ID NUMBER (WSCl, 1992)
 2-51B  UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
 2-51A  LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
 SB-6  SOIL BORING LOCATION AND ID NUMBER (WSCl, 1992)
 1-S2  SOIL BORING LOCATION AND ID NUMBER (ERI, 1990)
 SB-008  SOIL BORING LOCATION AND ID NUMBER (IT, 1994)
 #402  LOCATION OF INACTIVE/CLOSED UNDERGROUND STORAGE TANK
 --- FENCE
 ---100--- CONTOUR INTERVAL (DASHED WHERE INFERRED)
 4,600(9') TOTAL BTEX CONCENTRATION (DEPTH OF SOIL BELOW GROUND SURFACE)
 CONCENTRATIONS FROM <8 TO 100 µg/kg
 CONCENTRATIONS FROM 100 TO 1000 µg/kg
 CONCENTRATIONS FROM 1000 TO 10,000 µg/kg
 CONCENTRATIONS FROM 10,000 TO 100,000 µg/kg
 CONCENTRATIONS OVER 100,000 µg/kg



0 30
FEET

FIGURE 2.16
TOTAL BTEX CONCENTRATIONS
IN SOIL AT APPROXIMATELY
10 FEET BGS
AREA A SERVICE STATION

Sites FTA 2 and Area A
 RNA TS
 Tinker AFB, Oklahoma

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

2.1.4.2 Groundwater Quality

Groundwater samples have been collected during sampling events in January 1994, January 1995, October 1995, and August 1996 (IT, 1996; and Tinker AFB, 1996). Groundwater samples were analyzed for BTEX, VOCs, SVOCs, metals, and general chemistry. In addition, a temporary well sampling event was conducted from April to May, 1995 (IT, 1995c). Analytical results for VOCs for 1996 sampling are summarized in Table 2.5. Summary tables for previous sampling events are included in Appendix C.

BTEX compounds were detected in the USZ, but not in any samples collected from the LSZ. The highest concentrations of BTEX compounds detected in the USZ for August 1996 were from monitoring well 2-50B, with the sample containing 12,000 µg/L of benzene, 2,200 µg/L of ethylbenzene, 17,000 µg/L of toluene, and 9,300 µg/L of total xylenes. Well 2-50B is located at the northeastern fringe of the product plume. The BTEX plume extends towards the west and northwest, in the primary direction of USZ groundwater flow. Concentrations for total BTEX and the extent of free product from the January and April-May 1995 groundwater sampling events are shown on Figure 2.17.

Chlorinated solvents have been detected in both the USZ and the LSZ. In the USZ, maximum chlorinated solvent concentrations detected in August and September 1996 include 86 µg/L for TCE, 1,100 µg/L for *cis*-1,2-DCE, and 40 µg/L for 1,2-DCA. Other chlorinated solvents detected in earlier sampling events include low concentrations of PCE and VC. Figure 2.18 shows concentrations of CAHs detected in USZ and LSZ monitoring wells sampled in August and September 1996. High reporting limits for groundwater samples collected within the BTEX plume may hinder detection of lower concentrations of chlorinated solvents within the BTEX plume.

TABLE 2.5
SUMMARY OF VOLATILE ORGANIC COMPOUNDS IN AREA A GROUNDWATER
AUGUST TO SEPTEMBER 1996
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

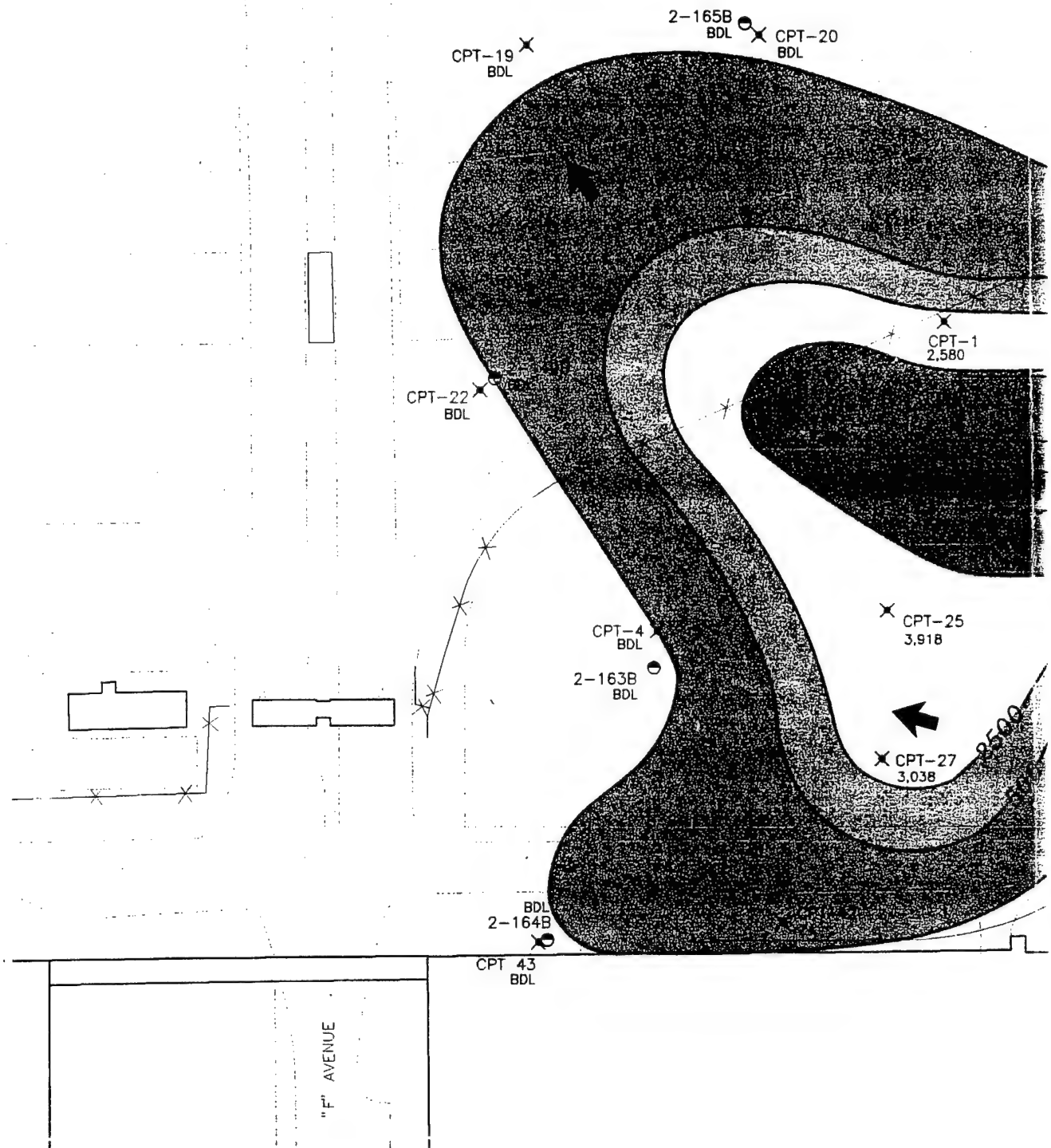
Sample Identification	Date Sampled	Units	1,2,4-Trimethylbenzene	1,2-Dichlorobenzene	1,2-Dichloroethane	1,3,5-Trimethylbenzene	Benzene	Carbon Tetrachloride	Chloroform	cis-1,2-Dichloroethene	Ethylbenzene	Isopropylbenzene	Methylene Chloride	Naphthalene	n-Propylbenzene	Toluene	Trichloroethene	Xylenes (Total)
Upper Saturated Zone																		
2-2	8/16/96	(µg/L) ^a	<12	<12	<12	<12	400	<12	<12	<12	<12	10J ^b	<12	16	19	<12	<12	<12
2-3	8/14/96	(µg/L)	<2	<2	<2	<2	110	<2	<2	75	210	36	10	86	43	25	86	89
2-4	8/16/96	(µg/L)	2500	<500	<500	820	9800	<500	<500	<500	1700	410J	<500	940	<500	14000	<500	9100
2-50B	8/14/96	(µg/L)	1700	<500	<500	470J	12000	<500	<500	1100	2200	<500	<500	980	1300	17000	<500	9300
2-51B	8/14/96	(µg/L)	9	<5	<5	<5	81	<5	<5	<5	8	<5	<5	24	<5	<5	<5	15
2-52B	8/15/96	(µg/L)	<1	<1	<1	<1	<1	<1	2	<1	<1	<1	0.9J	2	<1	<1	8	<1
2-163B	8/14/96	(µg/L)	<1	<1	40	<1	<1	<1	<1	<1	<1	<1	4	<1	<1	<1	<1	<1
2-164B	8/14/96	(µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	3	<1	<1	<1	<1	<1
2-165B	8/14/96	(µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2	<1	<1	<1	<1	<1
2-166B	8/14/96	(µg/L)	<1	1	<1	<1	<1	<1	0.9J	<1	<1	<1	2	<1	<1	<1	10	0.9J
2-264B	9/12/96	(µg/L)	<0.5	<0.5	<0.8	<0.5	<0.8	<1	<0.8	<0.5	<0.5	<0.8	1JB ^c	<0.8	<0.8	<0.8	<0.8	<0.5
2-265B	9/12/96	(µg/L)	<0.5	<0.5	<0.8	<0.5	<0.8	<1	0.4J	<0.5	<0.5	<0.8	2JB	<0.8	<0.8	<0.8	<0.8	<0.5
2-146B	8/14/96	(µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2	<1	<1	<1	0.8J	<1
Lower Saturated Zone																		
2-2A	8/16/96	(µg/L)	<5	<10	<5	<5	<5	38	4J	<5	<5	<5	<5	<5	<5	<5	120	<5
2-4A	8/15/96	(µg/L)	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	45	<2

Tinker AFB, 1996

a/ µg/L indicates micrograms per liter.

b/ J flag indicates an estimated concentration detected below the project reporting limit, but above the method detection limit.

c/ B flag indicates compound was detected in the method blank.

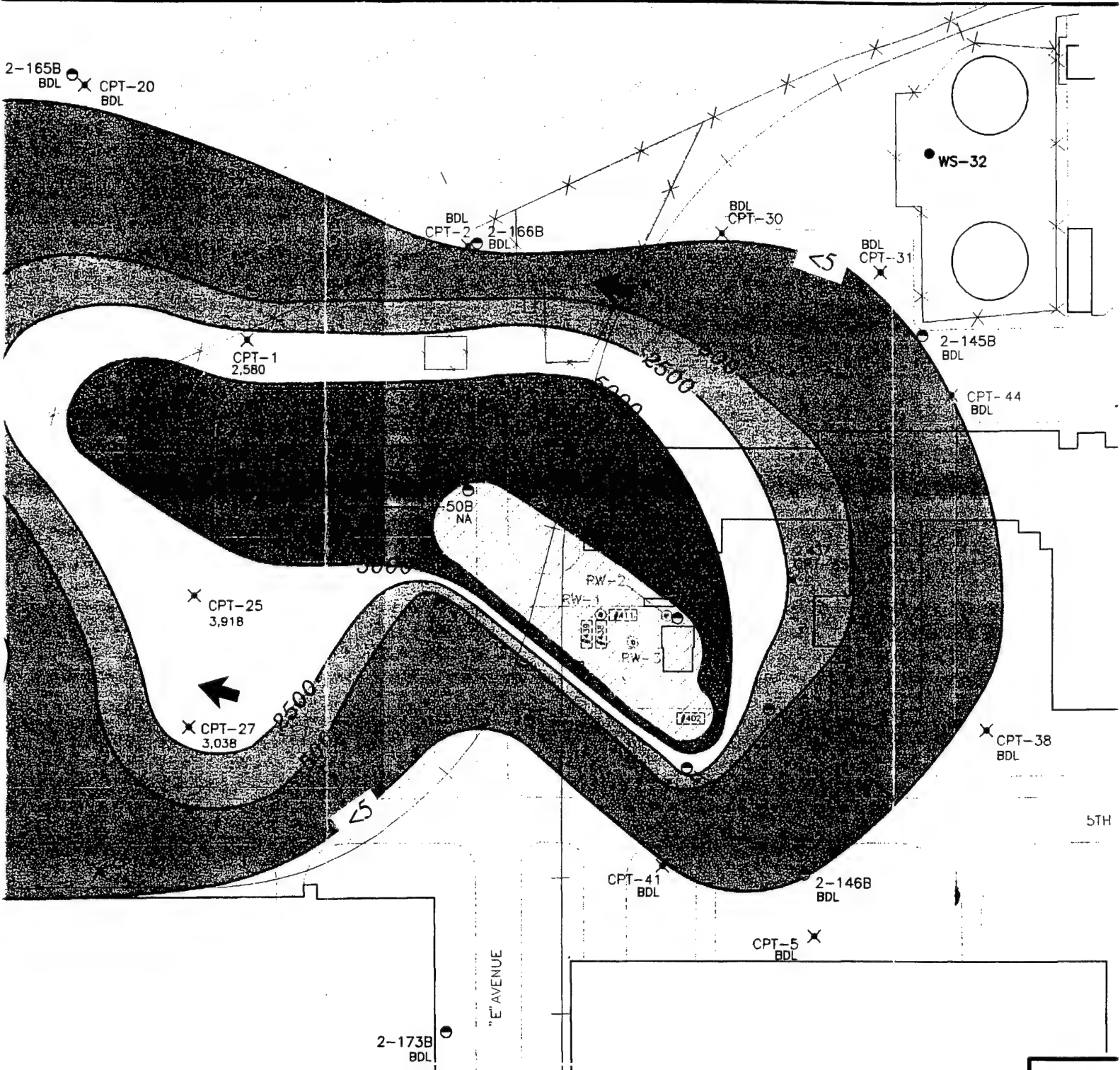


LEGEND

- CONCENTRATIONS FROM BDL TO 500 µg/L
- CONCENTRATIONS FROM 500 TO 2500 µg/L
- CONCENTRATIONS FROM 2500 TO 5000 µg/L
- CONCENTRATIONS OVER 5000 µg/L
- 500— LINES OF EQUAL BTEX CONCENTRATION (µg/L)
- AREA OF IDENTIFIED LIGHT NON-AQUEOUS PHASE LIQUID

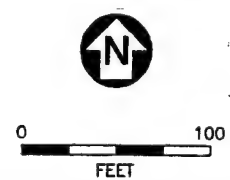
- EXISTING RECOVERY WELL LOCATION AND ID NUMBER (WSC, 1992)
- CPT-44 3,918 TEMPORARY GROUNDWATER PROBE SAMPLE LOCATION AND ID NUMBER AND TOTAL BTEX CONCENTRATION (µg/L)
- 2-51B 535 UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER AND JANUARY 1995 TOTAL BTEX CONCENTRATION (µg/L)
- DIRECTION OF GROUNDWATER FLOW

Source: IT, 1996.



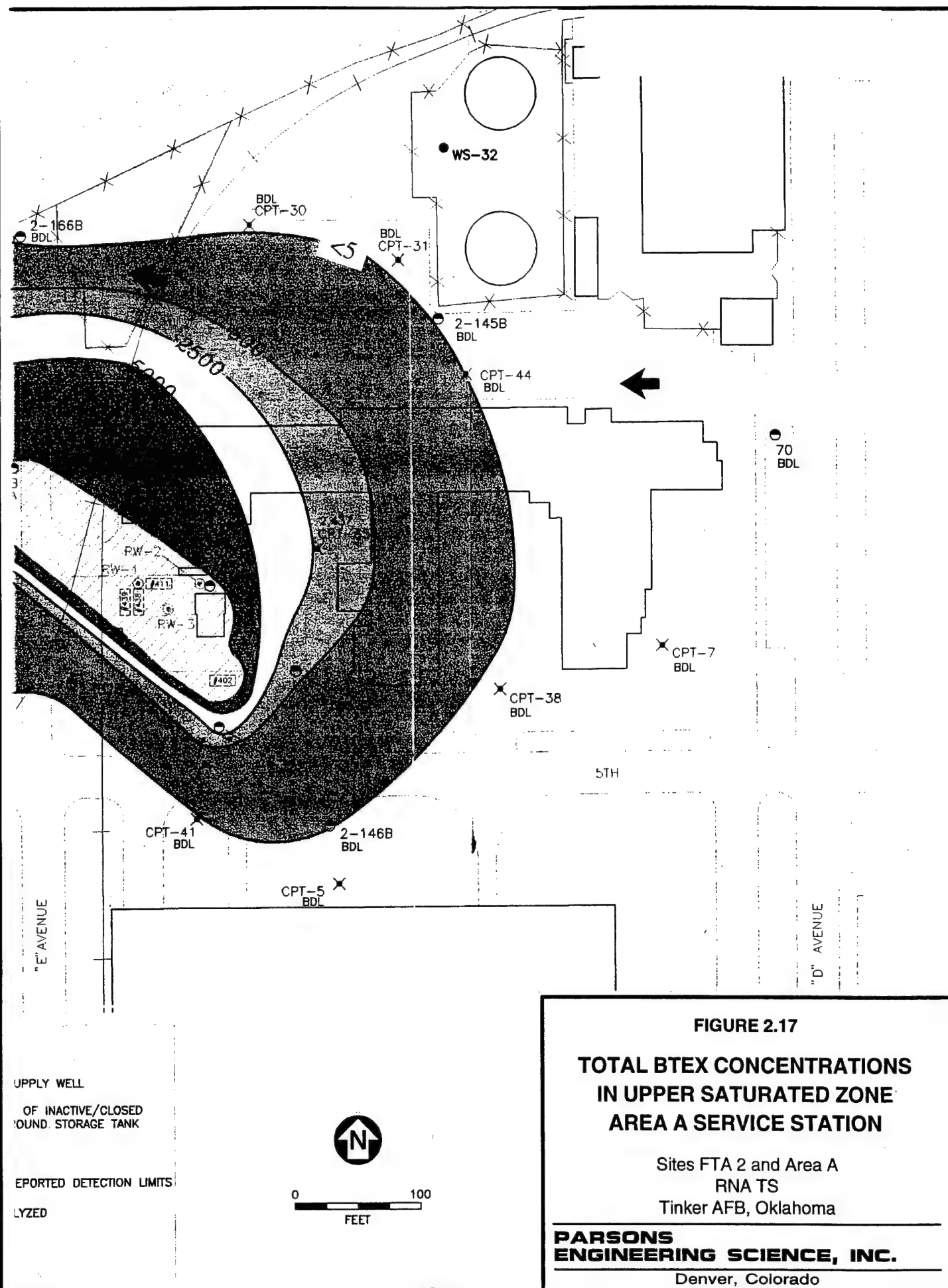
- 2-165B BDL CPT-20 BDL
- 2-166B BDL CPT-2 BDL
- 2-145B BDL CPT-31 BDL
- 2-146B BDL CPT-41 BDL
- 2-173B BDL CPT-5 BDL
- WS-32
- 50B NA
- CPT-1 2,580
- CPT-25 3,918
- CPT-27 3,038
- CPT-30 BDL
- CPT-31 BDL
- CPT-38 BDL
- CPT-44 BDL
- CPT-45 BDL
- CPT-46 BDL
- CPT-47 BDL
- CPT-48 BDL
- CPT-49 BDL
- CPT-50 BDL
- CPT-51 BDL
- CPT-52 BDL
- CPT-53 BDL
- CPT-54 BDL
- CPT-55 BDL
- CPT-56 BDL
- CPT-57 BDL
- CPT-58 BDL
- CPT-59 BDL
- CPT-60 BDL
- CPT-61 BDL
- CPT-62 BDL
- CPT-63 BDL
- CPT-64 BDL
- CPT-65 BDL
- CPT-66 BDL
- CPT-67 BDL
- CPT-68 BDL
- CPT-69 BDL
- CPT-70 BDL
- CPT-71 BDL
- CPT-72 BDL
- CPT-73 BDL
- CPT-74 BDL
- CPT-75 BDL
- CPT-76 BDL
- CPT-77 BDL
- CPT-78 BDL
- CPT-79 BDL
- CPT-80 BDL
- CPT-81 BDL
- CPT-82 BDL
- CPT-83 BDL
- CPT-84 BDL
- CPT-85 BDL
- CPT-86 BDL
- CPT-87 BDL
- CPT-88 BDL
- CPT-89 BDL
- CPT-90 BDL
- CPT-91 BDL
- CPT-92 BDL
- CPT-93 BDL
- CPT-94 BDL
- CPT-95 BDL
- CPT-96 BDL
- CPT-97 BDL
- CPT-98 BDL
- CPT-99 BDL

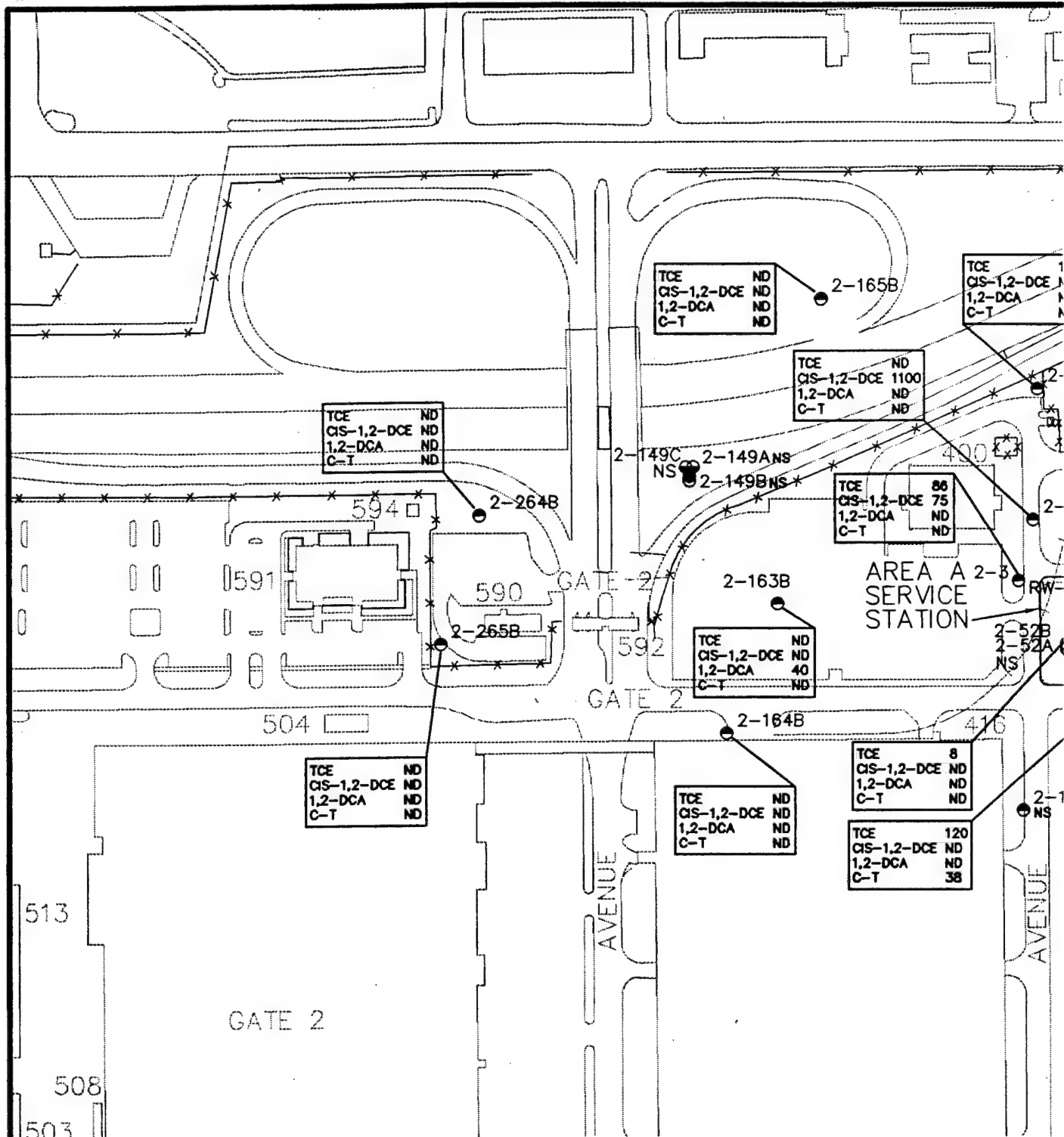
- WS-32 WATER SUPPLY WELL
- 50B NA LOCATION OF INACTIVE/CLOSED UNDERGROUND STORAGE TANK
- BDL BELOW REPORTED DETECTION LIMITS
- NA NOT ANALYZED



TOTAL IN AL

PARS ENGINE





LEGEND

- 2-165B ● UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- 2-2A ● LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- RW-1 ⊙ PRODUCT RECOVERY WELL
- WS-32 ● WATER SUPPLY WELL

- TCE TRICHLOROETHENE
- CIS-1,2-DCE CIS - 1,2 - DICHLOROETHENE
- 1,2-DCA 1,2 - DICHLOROETHANE
- C-T CARBON TETRACHLORIDE
- NS NOT SAMPLED
- ND NOT DETECTED

ALL CONCENTRATIONS IN MICROGRAMS PER LITER (μg/L)

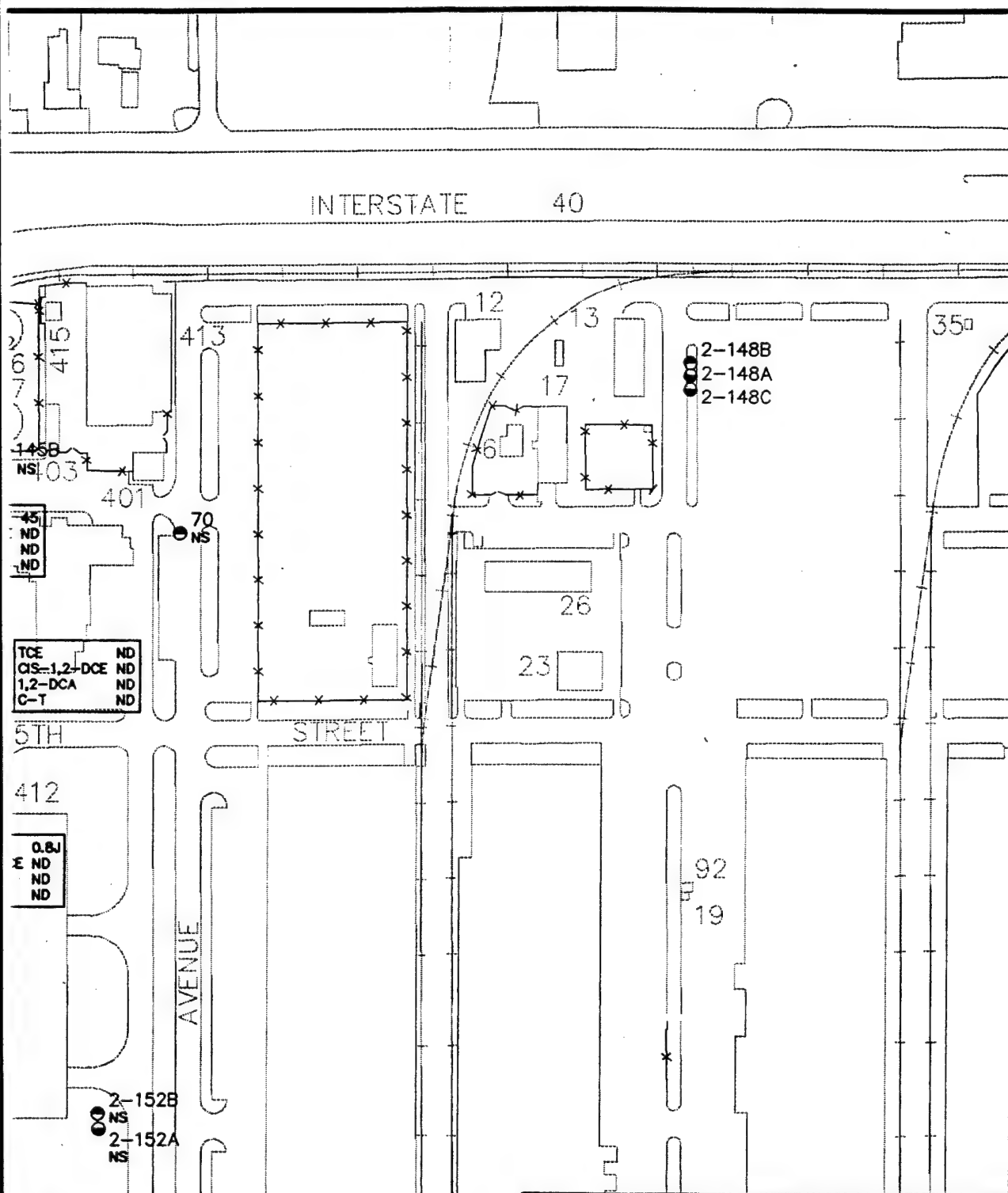


FIGURE 2.18
CHLORINATED ALIPHATIC
HYDROCARBONS DETECTED
IN GROUNDWATER
AUGUST TO SEPTEMBER 1996

Sites FTA 2 and Area A
 RNA TS
 Tinker AFB Oklahoma City, Oklahoma

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

In the LSZ, only the chlorinated solvents TCE and carbon tetrachloride were detected in August and September 1996 at concentrations of 120 µg/L and 38 µg/L, respectively, in the groundwater sample from well 2-2A. However, only data for two LSZ monitoring wells are available from that sampling event. Other chlorinated solvents detected in earlier sampling events include low concentrations (less than 2 µg/L) of PCE, *cis*-1,2-DCE, *trans*-1,2-DCE, and 1,2-DCA.

Only BTEX compounds and organic solvents are included as part of this RNA demonstration; therefore, results for other potential contaminants such as herbicides, PAHs, PCBs, pesticides, or metals are not summarized in this work plan. These compounds have been addressed in previous reports. Information on these compounds is presented by ERI (1990), WSCI (1992), and IT (1996).

2.2 DEVELOPMENT OF CONCEPTUAL MODELS

A conceptual model is a three-dimensional representation of a hydrogeologic system based on available geological, hydrological, climatological, and geochemical data. A site-specific conceptual model is developed to provide an understanding of the mechanisms controlling contaminant fate and transport and to identify additional data requirements. The model describes known and suspected sources of contamination, types of contamination, affected media, contaminant migration pathways, and potential receptor exposure points. The model also provides a foundation for formulating decisions regarding additional data collection and potential remedial actions. The conceptual models for FTA 2 and Area A will be used to aid in selecting additional data collection points and to identify appropriate data needs for modeling BTEX and chlorinated solvent attenuation using groundwater flow and solute transport models.

Successful conceptual model development involves:

- Defining the problem to be solved;

- Integrating available data, including
 - Local geologic and topographic data,
 - Hydraulic data,
 - Site stratigraphic data, and
 - Contaminant concentration and distribution data;
- Evaluating contaminant fate and transport characteristics;
- Identifying contaminant migration pathways;
- Identifying potential receptors and receptor exposure points; and
- Determining additional data requirements.

2.2.1 RNA and Groundwater Flow and Solute Transport Models

The positive effect of natural attenuation processes (e.g., advection, dispersion, sorption, and biodegradation) on reducing the actual mass of fuel-related contamination dissolved in groundwater has been termed RNA. To estimate the impact of natural attenuation on the fate and transport of BTEX and CAH compounds dissolved in groundwater at a site, two important lines of evidence must be demonstrated (Wiedemeier *et al.*, 1995). The first is a documented loss of contaminants at the field scale. One way to show loss of contaminant mass is to use historical monitoring data to show that plume concentrations and extents decrease or remain stable over time. At some sites, dissolved concentrations of biologically recalcitrant tracers found in most fuel contamination can be used in conjunction with aquifer hydrogeologic parameters, such as groundwater seepage velocity and dilution, to demonstrate that a reduction in contaminant mass is occurring. The second line of evidence involves the use of geochemical data to show that areas with dissolved BTEX and CAH contamination can

be correlated to areas with depleted electron acceptor (e.g., oxygen, nitrate, and sulfate) concentrations and increases in metabolic degradation byproduct concentrations (e.g., methane, ferrous iron, ethene, and chloride). With this site-specific information, groundwater flow and solute transport models can be used to simulate the fate and transport of dissolved BTEX and CAH compounds under the influence of natural attenuation.

Groundwater flow and solute transport models have proven useful for predicting plume migration and contaminant attenuation by natural biodegradation. Analytical and numerical models are available for modeling the fate and transport of BTEX and CAHs under the influence of advection, dispersion, sorption, and natural aerobic and anaerobic biodegradation. Analytical models derived from advection-dispersion equations [e.g., models such as those presented by Wexler (1992) and van Genuchten and Alves (1982)] may be useful. However, because BTEX and CAH biodegradation may be the result of different processes in different locations, it may be necessary to use a numerical model to incorporate spatial variability into the fate and transport analysis.

An accurate estimate of the potential for natural biodegradation of CAHs and BTEX compounds in groundwater is important to consider when determining whether groundwater contamination presents a substantial threat to human health and the environment, and when deciding what type of remedial alternative will be most cost effective in eliminating or abating these threats. Over the past two decades, numerous laboratory and field studies have demonstrated that subsurface microorganisms can degrade a variety of hydrocarbons and chlorinated solvents (Lee, 1988; McCarty *et al.*, 1992). The following sections discuss the biodegradation of BTEX and CAHs.

2.2.2 Biodegradation of Dissolved BTEX Contamination

Numerous laboratory and field studies have shown that hydrocarbon-degrading bacteria can participate in the degradation of many of the chemical components of fuel hydrocarbons, including the BTEX compounds (e.g., Jamison *et al.*, 1975; Atlas, 1981, 1984, 1988; Gibson and Subramanian, 1984; Reinhard *et al.*, 1984; Young, 1984; Bartha, 1986; Wilson *et al.*, 1986, 1987, and 1990; Barker *et al.*, 1987; Baedecker *et al.*, 1988; Lee, 1988; Chiang *et al.*, 1989; Grbic-Galic, 1989 and 1990; Cozzarelli *et al.*, 1990; Leahy and Colewell, 1990; Altenschmidt and Fuchs, 1991; Alvarez and Vogel, 1991; Baedecker and Cozzarelli, 1991; Ball *et al.*, 1991; Bauman, 1991; Borden, 1991; Brown *et al.*, 1991; Edwards *et al.*, 1991 and 1992; Evans *et al.*, 1991a and 1991b; Haag *et al.*, 1991; Hutchins and Wilson, 1991; Hutchins *et al.*, 1991a and 1991b; Beller *et al.*, 1992; Bouwer, 1992; Edwards and Grbic-Galic, 1992; Edwards *et al.*, 1992; Thierrin *et al.*, 1992; Malone *et al.*, 1993; Davis *et al.*, 1994). Biodegradation of fuel hydrocarbons can occur when an indigenous population of hydrocarbon-degrading microorganisms is present in the aquifer and sufficient concentrations of electron acceptors and nutrients, including fuel hydrocarbons, are available to these organisms.

Microorganisms obtain energy for cell production and maintenance by facilitation of thermodynamically advantageous reduction/oxidation (redox) reactions involving the transfer of electrons from electron donors to available electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. Electron donors at FTA 2 and Area A may include natural organic carbon and fuel hydrocarbon compounds. Fuel hydrocarbons are completely degraded or detoxified if they are utilized as the primary electron donor for microbial metabolism (Bouwer, 1992). Electron acceptors are elements or compounds that occur in relatively oxidized states, and include dissolved oxygen (DO), nitrate, ferric iron, sulfate, and carbon dioxide.

The driving force of BTEX degradation is electron transfer, which is quantified by the Gibbs free energy of the reaction (ΔG°) (Stumm and Morgan, 1981; Bouwer, 1994; Godsey, 1994). The value of ΔG° represents the quantity of free energy consumed or yielded to the system during the reaction. Table 2.6 lists stoichiometry of the redox equations involving BTEX and the resulting ΔG° . Although thermodynamically favorable, most of the reactions involved in BTEX oxidation cannot proceed abiotically because of the lack of activation energy. Microorganisms are capable of providing the necessary activation energy; however, they will facilitate only those redox reactions that have a net yield of energy (i.e., $\Delta G^\circ < 0$). Microorganisms preferentially utilize electron acceptors while metabolizing fuel hydrocarbons (Bouwer, 1992). DO is utilized first as the prime electron acceptor. After the DO is consumed, anaerobic microorganisms typically use electron acceptors (as available) in the following order of preference: nitrate, ferric iron hydroxide, sulfate, and finally carbon dioxide. Because the biodegradation of fuel hydrocarbons should deplete the concentrations of these electron acceptors, construction of isopleth maps depicting their concentrations can provide evidence of whether biodegradation is occurring, and the degree to which it is occurring.

Depending on the types and concentrations of electron acceptors present (e.g., nitrate, ferric iron, sulfate, carbon dioxide), pH conditions, and redox potential, anaerobic biodegradation can occur by denitrification, ferric iron reduction, sulfate reduction, or methanogenesis. Other, less common anaerobic degradation mechanisms such as manganese or nitrate reduction may dominate if the physical and chemical conditions in the subsurface favor use of these electron acceptors. Anaerobic destruction of BTEX compounds is associated with the accumulation of fatty acids, production of methane, solubilization of iron, and reduction of nitrate and sulfate (Cozzarelli *et al.*, 1990; Wilson *et al.*, 1990). Environmental conditions and microbial competition will ultimately determine which processes will dominate. Vrobesky and

TABLE 2.6
COUPLED OXIDATION REACTIONS FOR BTEX COMPOUNDS
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

Coupled Benzene Oxidation Reactions	ΔG°_r (kcal/mole Benzene)	ΔG°_r (kJ/mole Benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$7.5O_2 + C_6H_6 \Rightarrow 6CO_{2,g} + 3H_2O$ <i>Benzene oxidation / aerobic respiration</i>	-765.34	-3202	3.07:1
$6NO_3 + 6H^+ + C_6H_6 \Rightarrow 6CO_{2,g} + 6H_2O + 3N_{2,g}$ <i>Benzene oxidation / denitrification</i>	-775.75	-3245	4.77:1
$3.75NO_3^- + C_6H_6 + 7.5H^+ + 0.75H_2O \Rightarrow 6CO_2 + 3.75NH_4^+$ <i>Benzene oxidation / nitrate reduction</i>	-524.1	-2193	2.98:1
$60H^+ + 30Fe(OH)_{3,a} + C_6H_6 \Rightarrow 6CO_2 + 30Fe^{2+} + 78H_2O$ <i>Benzene oxidation / iron reduction</i>	-560.10	-2343	21.5:1 ^{a/}
$75H^+ + 3.75SO_4^{2-} + C_6H_6 \Rightarrow 6CO_{2,g} + 3.75H_2S^o + 3H_2O$ <i>Benzene oxidation / sulfate reduction</i>	-122.93	-514.3	4.61:1
$4.5H_2O + C_6H_6 \Rightarrow 2.25CO_{2,g} + 3.75CH_4$ <i>Benzene oxidation / methanogenesis</i>	-32.40	-135.6	0.77:1 ^{b/}

Coupled Toluene Oxidation Reactions	ΔG°_r (kcal/mole Toluene)	ΔG°_r (kJ/mole Toluene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$9O_2 + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 4H_2O$ <i>Toluene oxidation / aerobic respiration</i>	-913.76	-3823	3.13:1
$7.2NO_3 + 7.2H^+ + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 7.6H_2O + 3.6N_{2,g}$ <i>Toluene oxidation / denitrification</i>	-926.31	-3875	4.85:1
$72H^+ + 36Fe(OH)_{3,a} + C_6H_5CH_3 \Rightarrow 7CO_2 + 36Fe^{2+} + 94H_2O$ <i>Toluene oxidation / iron reduction</i>	-667.21	-2792	21.86:1 ^{a/}
$9H^+ + 4.5SO_4^{2-} + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 4.5H_2S^o + 4H_2O$ <i>Toluene oxidation / sulfate reduction</i>	-142.86	-597.7	4.7:1
$5H_2O + C_6H_5CH_3 \Rightarrow 2.5CO_{2,g} + 4.5CH_4$ <i>Toluene oxidation / methanogenesis</i>	-34.08	-142.6	0.78:1 ^{b/}

TABLE 2.6 (Continued)
COUPLED OXIDATION REACTIONS FOR BTEX COMPOUNDS
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

Coupled Ethylbenzene Oxidation Reactions	ΔG°_r (kcal/mole Ethyl- benzene)	ΔG°_r (kJ/mole Ethyl- benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5 O_2 + C_6H_5C_2H_5 \Rightarrow 8CO_{2,r} + 5H_2O$ <i>Ethylbenzene oxidation / aerobic respiration</i>	-1066.13	-4461	3.17:1
$8.4 NO_3^- + 8.4 H^+ + C_6H_5C_2H_5 \Rightarrow 8CO_{2,r} + 9.2H_2O + 4.2N_{2,r}$ <i>Ethylbenzene oxidation / denitrification</i>	-1080.76	-4522	4.92:1
$84H^+ + 42Fe(OH)_{3,a} + C_6H_5C_2H_5 \Rightarrow 8CO_2 + 42Fe^{2+} + 110H_2O$ <i>Ethylbenzene oxidation / iron reduction</i>	-778.48	-3257	22:1 ^{a/}
$10.5 H^+ + 5.25 SO_4^{2-} + C_6H_5C_2H_5 \Rightarrow 8CO_{2,r} + 5.25 H_2S^o + 5H_2O$ <i>Ethylbenzene oxidation / sulfate reduction</i>	-166.75	-697.7	4.75:1
$5.5 H_2O + C_6H_5C_2H_5 \Rightarrow 2.75 CO_{2,r} + 5.25 CH_4$ <i>Ethylbenzene oxidation / methanogenesis</i>	-39.83	-166.7	0.79:1 ^{b/}

Coupled m-Xylene Oxidation Reactions	ΔG°_r (kcal/mole <i>m</i> -xylene)	ΔG°_r (kJ/mole <i>m</i> -xylene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5 O_2 + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,r} + 5H_2O$ <i>m-Xylene oxidation / aerobic respiration</i>	-1063.25	-4448	3.17:1
$8.4 NO_3^- + 8.4 H^+ + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,r} + 9.2H_2O + 4.2N_{2,r}$ <i>m-Xylene oxidation / denitrification</i>	-1077.81	-4509	4.92:1
$84H^+ + 42Fe(OH)_{3,a} + C_6H_4(CH_3)_2 \Rightarrow 8CO_2 + 42Fe^{2+} + 110H_2O$ <i>m-Xylene oxidation / iron reduction</i>	-775.61	-3245	22:1 ^{a/}
$10.5 H^+ + 5.25 SO_4^{2-} + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,r} + 5.25 H_2S^o + 5H_2O$ <i>m-Xylene oxidation / sulfate reduction</i>	-163.87	-685.6	4.75:1
$5.5 H_2O + C_6H_4(CH_3)_2 \Rightarrow 2.75 CO_{2,r} + 5.25 CH_4$ <i>m-Xylene oxidation / methanogenesis</i>	-36.95	-154.6	0.79:1 ^{b/}

^{a/} Mass of ferrous iron produced during microbial respiration.

^{b/} Mass of methane produced during microbial respiration.

Chapelle (1994) show that the dominant terminal electron accepting process can vary both temporally and spatially in an aquifer with fuel hydrocarbon contamination.

2.2.3 Biodegradation of CAHs

Chlorinated solvents can be transformed, directly or indirectly, by biological processes (e.g., Bouwer *et al.*, 1981; Wilson and Wilson, 1985; Miller and Guengerich, 1982; Nelson *et al.*, 1986; Bouwer and Wright, 1988; Little *et al.*, 1988; Mayer *et al.*, 1988; Arciero *et al.*, 1989; Cline and Delfino, 1989; Freedman and Gossett, 1989; Folsom *et al.*, 1990; Harker and Kim, 1990; Alvarez-Cohen and McCarty, 1991a, 1991b; DeStefano *et al.*, 1991; Henry, 1991; McCarty *et al.*, 1992; Hartmans and de Bont, 1992; McCarty and Semprini, 1994; Vogel, 1994). CAHs may undergo biodegradation through three different pathways: use as an electron acceptor, use as an electron donor, or cometabolism, which is degradation resulting from exposure to a catalytic enzyme fortuitously produced during an unrelated process. At a given site, one or all of these processes may be operating, although at many sites the use of CAHs as electron acceptors appears to be the most important.

In a pristine aquifer, native organic carbon is utilized as an electron donor and dissolved oxygen (DO) is utilized first as the prime electron acceptor. Where anthropogenic carbon (e.g., fuel hydrocarbons or less chlorinated CAHs) is present, it also will be utilized as an electron donor. After the DO is consumed, anaerobic microorganisms typically use native electron acceptors (as available) in the following order of preference: nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluation of the distribution of these electron acceptors can provide evidence of where and how CAH biodegradation is occurring. In addition, because CAHs may be used as electron acceptors or electron donors (in competition with other acceptors or donors), maps showing the distribution of these compounds will also provide evidence on the types of biodegradation processes acting at a site.

As with BTEX, the driving force behind redox reactions resulting in CAH degradation is electron transfer. Although thermodynamically favorable, most of the reactions involved in CAH reduction and oxidation cannot proceed abiotically because of the lack of activation energy. Microorganisms are capable of providing the necessary activation energy; however, they will facilitate only those redox reactions that have a net yield of energy. A more complete description of the main types of biodegradation reactions affecting CAHs is presented in the following subsections.

2.2.3.1 Electron Acceptor Reactions (Reductive Dechlorination)

Under anaerobic conditions, biodegradation of chlorinated solvents usually proceeds through a process called reductive dehalogenation. During this process, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a halogen atom is removed and replaced with a hydrogen atom. Figure 2.19 illustrates the transformation of chlorinated ethenes via reductive dehalogenation. In general, reductive dehalogenation occurs by sequential dechlorination from PCE to TCE to DCE to VC to ethene. Depending upon environmental conditions, this sequence may be interrupted, with other processes then acting upon the products. During reductive dehalogenation, all three isomers of DCE can theoretically be produced; however, Bouwer (1994) reports that under the influence of biodegradation, *cis*-1,2-DCE is a more common intermediate than *trans*-1,2-DCE, and that 1,1-DCE is the least prevalent intermediate of the three DCE isomers. Reductive dehalogenation of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in chloride.

Reductive dehalogenation affects each of the chlorinated ethenes differently. PCE is the most susceptible of these compounds to reductive dehalogenation because it is the most oxidized. Conversely, VC is the least susceptible to reductive dehalogenation

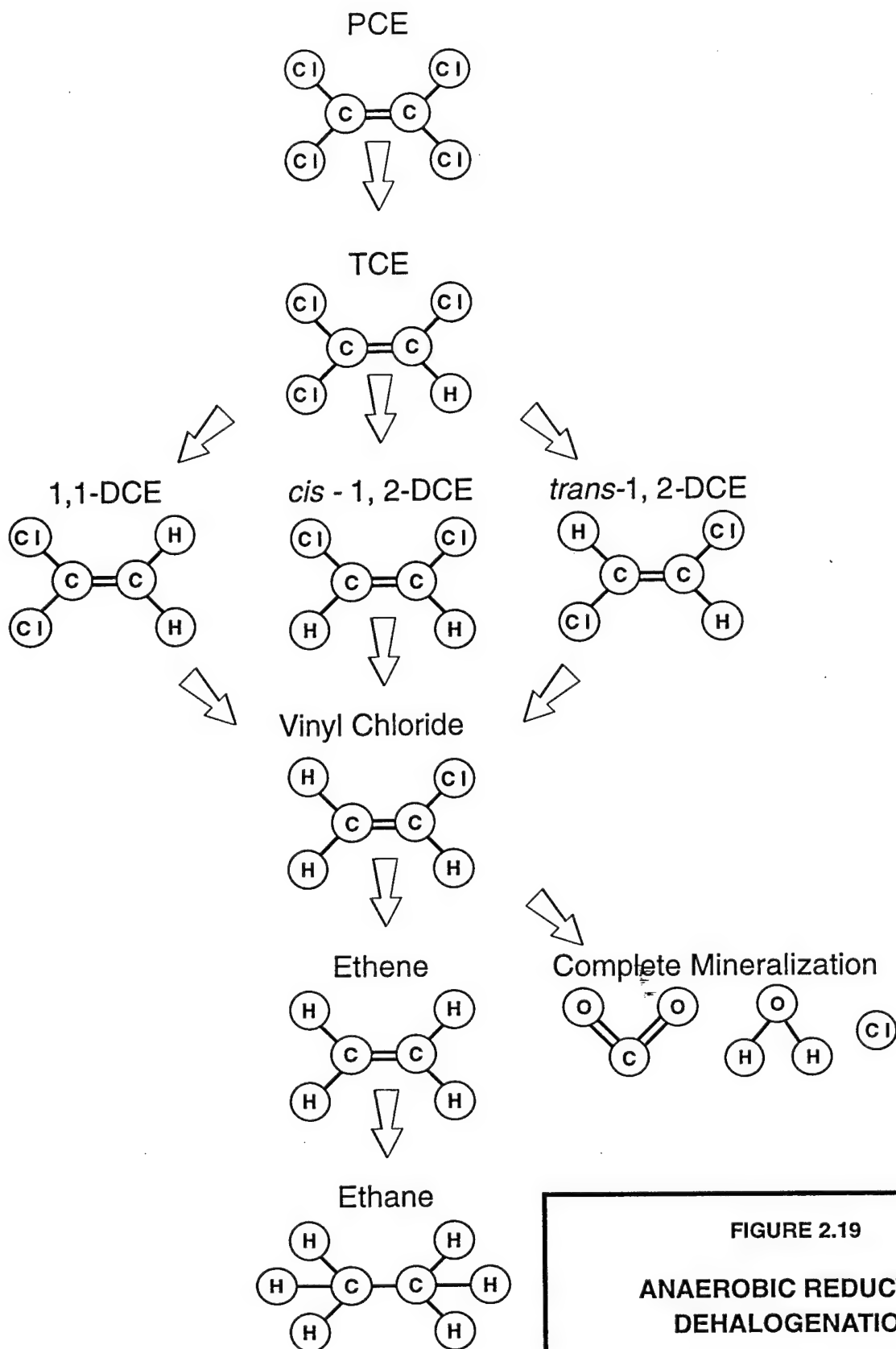


FIGURE 2.19

**ANAEROBIC REDUCTIVE
DEHALOGENATION**

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

because it is the least oxidized of these compounds. The rate of reductive dehalogenation also has been observed to decrease as the degree of chlorination decreases (Vogel and McCarty, 1985; Bouwer, 1994). Murray and Richardson (1993) have postulated that this rate decrease may explain the accumulation of VC in PCE and TCE plumes that are undergoing reductive dechlorination. Reductive dehalogenation has been demonstrated under nitrate- and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of CAHs, occur under methanogenic conditions (Bouwer, 1994).

Because CAH compounds are used as electron acceptors, there must be an appropriate source of carbon for microbial growth in order for reductive dehalogenation to occur (Bouwer, 1994). Potential carbon sources can include low-molecular-weight compounds (e.g., lactate, acetate, methanol, or glucose) present in natural organic matter, fuel hydrocarbons, or less-chlorinated compounds such as VC, DCE, or DCA.

2.2.3.2 Electron Donor Reactions

Under aerobic conditions some CAH compounds can be utilized as the primary substrate (i.e., electron donor) in biologically mediated redox reactions (McCarty and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded CAH. In contrast to reactions in which the CAH is used as an electron acceptor, only the least oxidized CAHs can be utilized as electron donors in biologically mediated redox reactions. McCarty and Semprini (1994) describe investigations in which VC and 1,2-dichloroethane (DCA) were shown to serve as primary substrates. These authors also document that dichloromethane has the potential to function as a primary substrate in either aerobic or anaerobic environments. In addition, Bradley and Chapelle (1996) show evidence of mineralization of VC under iron-reducing conditions so long as there is sufficient bioavailable iron (III). Klier *et al.*, (1996) demonstrated aerobic mineralization of all 3

isomers of DCE. Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using TCE and PCE. Aerobic metabolism of VC, DCA, or DCE may be characterized by a loss of VC, DCA, or DCE mass or a decreasing molar ratio of VC, DCA, or DCE to other CAH compounds.

2.2.3.3 Cometabolism

When a CAH is biodegraded through cometabolism, it serves as neither an electron acceptor nor a primary substrate in a biologically mediated redox reaction. Instead, the degradation of the CAH is catalyzed by an enzyme or cofactor that is fortuitously produced by organisms for other purposes. The organism receives no known benefit from the degradation of the CAH; rather the cometabolic degradation of the CAH may in fact be harmful to the microorganism responsible for the production of the enzyme or cofactor (McCarty and Semprini, 1994).

Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions. Aerobic biodegradation pathways for chlorinated ethenes are illustrated in Figure 2.20. It has been reported that under aerobic conditions chlorinated ethenes, with the exception of PCE, are susceptible to cometabolic degradation (Murray and Richardson, 1993; Vogel, 1994; McCarty and Semprini, 1994). Vogel (1994) further elaborates that the cometabolism rate increases as the degree of dechlorination decreases.

During the cometabolic process, TCE is indirectly transformed by bacteria as an organic carbon substrate is used to meet their energy requirements. Therefore, TCE does not enhance the degradation of carbon sources, nor will its cometabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources. It is likely that depletion of suitable substrates (organic carbon sources) may limit cometabolism of CAHs.

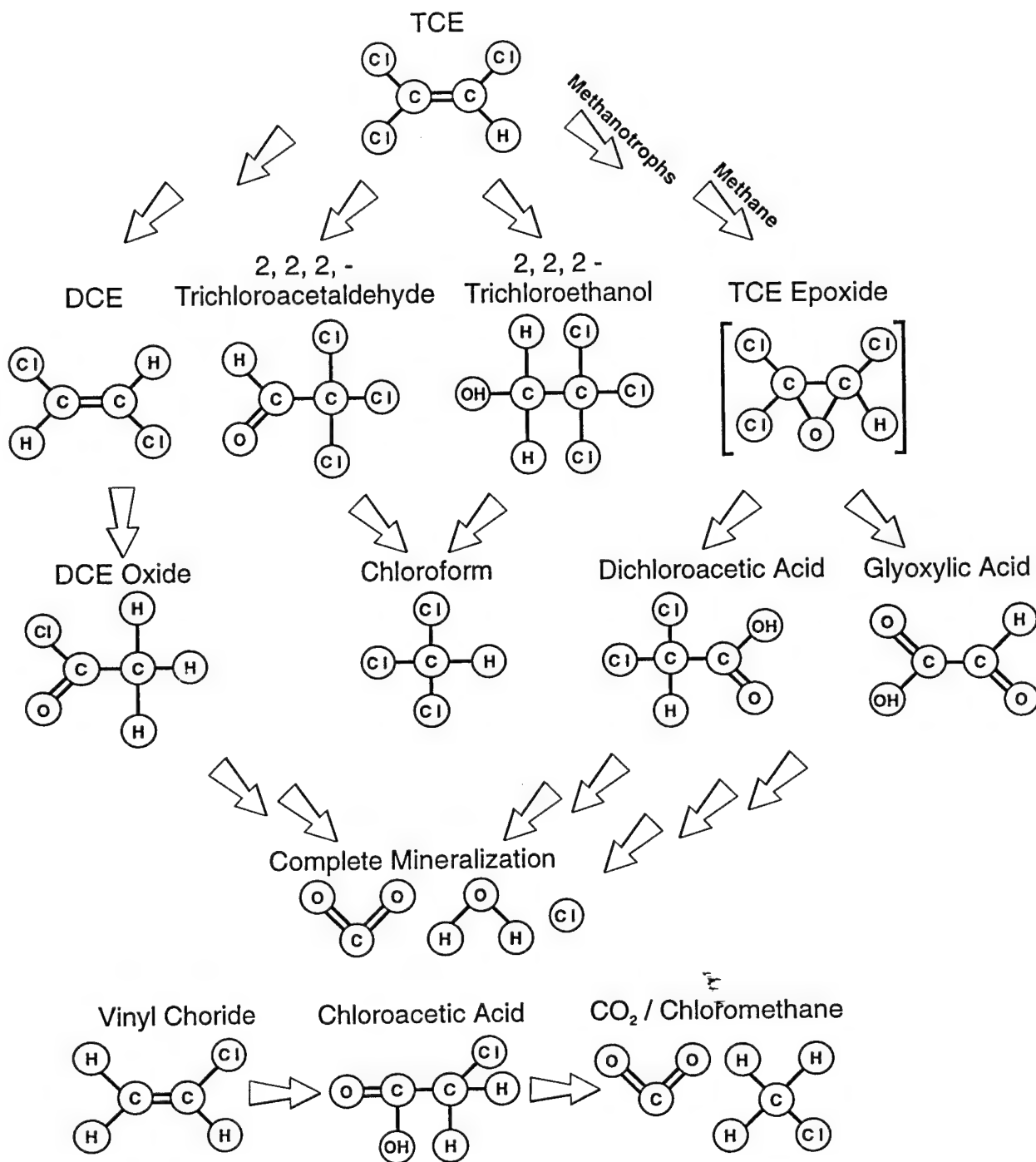


FIGURE 2.20

AEROBIC BIODEGRADATION PATHWAYS

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

2.2.3.4 Behavior of Chlorinated Solvent Plumes

Chlorinated solvent plumes can exhibit three types of behavior depending on the amount of solvent, the amount of organic (native and/or anthropogenic) organic carbon in the aquifer, the distribution and concentration of natural electron acceptors, and the types of electron acceptors being utilized. Individual plumes may exhibit all three types of behavior in different portions of the plume. The different types of plume behavior are summarized below.

2.2.3.4.1 Type 1 Behavior

Type 1 behavior occurs where the primary substrate is anthropogenic carbon (e.g., BTEX or landfill leachate) and this anthropogenic carbon drives reductive dechlorination. When evaluating RNA of a plume exhibiting type 1 behavior the following questions must be answered:

1. Does electron acceptor supply exceed demand (i.e., is the electron acceptor supply adequate)? Will the microorganisms degrading the CAH plume strangle before they starve [i.e., will they run out of CAHs (electron acceptors) before they run out of primary substrate (anthropogenic carbon)]?
2. What is the role of competing electron acceptors?
3. Are VC and DCE oxidized or reduced?

2.2.3.4.2 Type 2 Behavior

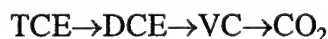
Type 2 behavior dominates in areas that are characterized by relatively high native organic carbon concentrations, and this carbon source drives reductive dechlorination (i.e., the primary substrate for microorganism growth is native organic carbon). When evaluating RNA of a type 2 chlorinated solvent plume, the same questions as those posed in the description of type 1 behavior must be answered.

2.2.3.4.3 Type 3 Behavior

Type 3 behavior dominates in areas that are characterized by low native and/or anthropogenic carbon concentrations where dissolved oxygen concentrations are greater than 1.0 milligrams per liter (mg/L). Under these conditions the plume is aerobic and reductive dechlorination will not occur. Thus there is no biodegradation of PCE and TCE, and natural attenuation mechanisms for these compounds are advection, dispersion, and sorption only. However, VC, DCA, and DCE can be oxidized under these conditions.

2.2.3.4.4 Mixed Behavior

As mentioned above, a single chlorinated solvent plume can exhibit all three types of behavior in different portions of the plume. This can be beneficial for natural biodegradation of CAH plumes. For example Wiedemeier *et al.* (1996b) describe a plume at Plattsburgh AFB, New York that exhibits type 1 behavior in the source area and type 3 behavior downgradient from the source. The best scenario involves a plume in which TCE and DCE are reductively dechlorinated (type 1 or 2 behavior), then VC is oxidized (type 3 behavior), either aerobically or anaerobically (via iron reduction). Vinyl chloride is oxidized to carbon dioxide in this type of plume and does not accumulate. The following sequence of reactions occurs in this type of plume.



In general, the TCE, DCE, and VC are attenuated at approximately the same rate, and thus these reactions may be confused with simple dilution. Note that no ethene is produced during this reaction. Vinyl chloride is removed from the system much faster under these conditions than it is under VC-reducing conditions.

A less desirable scenario involves a plume in which all CAHs are reductively dechlorinated (type 2 or 3 behavior). Vinyl chloride is reduced to ethene which is

further reduced to ethane. The following sequence of reactions occur in this type of plume.



In this type of plume, DCE and VC degrade more slowly than TCE, and thus they tend to accumulate. This is the type of reductive dechlorination described by Freedman and Gossett (1989).

2.2.4 Initial Conceptual Model

2.2.4.1 Initial Conceptual Model for FTA 2

Geologic and hydrogeologic data for FTA 2 were previously integrated to produce a geologic cross-section of the site (Figure 2.7). The cross-section shown on Figure 2.7 illustrates the stratigraphy through the site from north to south, perpendicular to the direction of groundwater flow in both the USZ and the LSZ.

Figure 2.8 is a groundwater contour map of the USZ for FTA 2 prepared using September 1996 groundwater elevation data. Groundwater is present approximately 7 to 25 feet bgs. The groundwater flow direction for the USZ at FTA 2 is generally west to southwest. Figure 2.9 is a groundwater contour map of the LSZ for September 1996. The LSZ receives limited vertical recharge due to the aquitard of clay and hard silt deposits below the shallow sand and gravel USZ aquifer. On the basis of available data, Parsons ES will model this site as an unconfined, fine-grained sand aquifer in the USZ, with an unconfined to semi-confined, fine-grained sand lower aquifer (LSZ), separated from the USZ by an semi-confining aquitard of hard silt and clay. This conceptual model will be modified as necessary as additional site hydrogeologic data become available.

Given available information, it appears that the CAH plume originating at FTA 2 is a Type 2 or mixed (Type 2 and Type 3) behavior plume. Residual fuel hydrocarbons from fire training exercises, including TPH, may provide the area with a source of carbon; however with the existing data no conclusions can be drawn. Biodegradation of TCE to 1,2-DCE (primarily the *cis* isomer) appears to be occurring, but the scarcity of other degradation products such as VC indicates that the degradation process has not proceeded further. The relatively high concentrations of *cis*-1,2-DCE and high ratios of *cis*-1,2-DCE to *trans*-1,2-DCE near the TCE source area (well 2-62B) indicate that biodegradation is occurring in that area. There is limited geochemical data for electron acceptor concentrations. Nevertheless, conditions appear to be sufficient for limited reductive dehalogenation of TCE in the source area.

For the purposes of this demonstration, CAHs are the chemicals of concern in groundwater at Site FTA 2 (Table 2.4 and Figures 2.14 and 2.15) and will be the primary focus of this RNA study because of their regulatory importance. The effects of fate and transport processes on the dissolved CAHs will be investigated using quantitative groundwater analytical data and analytical solute-transport models. Data collection and analysis requirements are discussed in Section 3 of this work plan.

2.2.4.2 Initial Conceptual Model for Area A

The Area A geologic data were previously integrated to produce hydrogeologic cross-sections of the site (Figures 2.10 and 2.11). The cross-section shown on Figure 2.10 illustrates the stratigraphy through the site from north to south. The cross-section shown on Figure 2.11 illustrates the stratigraphy through the site from east to west, the primary direction of groundwater flow in both the USZ and the LSZ.

Shallow groundwater (USZ) is encountered at approximately 8 to 19 feet bgs at Area A, and the groundwater flow direction is west to southwest. The LSZ receives limited recharge due to the confining to semi-confining aquitard layer of clay and hard silt

deposits below the shallow sand USZ. On the basis of available data, Parsons ES will model this site as an unconfined, fine-grained sand aquifer in the USZ, with an unconfined fine-grained sand lower aquifer (LSZ), separated from the USZ by an semi-confining aquitard of hard silt and clay. This conceptual model will be modified as necessary as additional site hydrogeologic data become available.

Mobile LNAPL (free product) may be encountered at Area A. If mobile LNAPL is encountered, it may be necessary to use the fuel/water partitioning models of Bruce *et al.* (1991) or Cline *et al.* (1991) to provide a conservative source term to model the partitioning of BTEX (and possible cosolvenated CAH compounds) from the free-phase product into the groundwater. In order to use one of these models, samples of free product will be collected and analyzed for mass fraction of BTEX and CAH. If mobile LNAPL is present, Parsons ES will attempt to collect groundwater samples from immediately below the LNAPL layer, if possible.

For the purposes of this demonstration, BTEX compounds and CAHs are the chemicals of concern in groundwater at Area A (Table 2.5, and Figures 2.16 and 2.17) and will be the primary focus of this RNA study because of their regulatory importance. BTEX is expected to continue to partition from mobile and residual LNAPL in the USZ smear zone into the groundwater, and to migrate downgradient as a dissolved contaminant plume. CAHs are expected to originate and to continue to migrate from an offsite source through the USZ and LSZ beneath Area A. In addition to the effects of mass transport mechanisms (volatilization, dispersion, diffusion, and adsorption), dissolved contaminants will likely be removed from the groundwater system by naturally occurring destructive attenuation mechanisms, such as biodegradation.

Given available information, it is suspected that the CAH plume originating at Area A is a Type 1 behavior plume in the USZ, and a Type 3 or mixed (Type 2 and Type 3)

behavior plume in the LSZ. Fuel hydrocarbons provide the USZ plume with a source of carbon, including elevated concentrations of BTEX. This combination of contaminants in the USZ appears to result in conditions that are favorable for the reductive dehalogenation of CAHs. BTEX contamination is not migrating to the LSZ. If biodegradation is occurring in the LSZ, it is difficult to evaluate because only very low concentrations of DCE have been detected. Furthermore, these concentrations of DCE may be the result of USZ biodegradation followed by migration to the LSZ. There is limited geochemical data for electron acceptor concentrations. Therefore, it is unknown whether groundwater conditions are acceptable for biodegradation of TCE in the LSZ.

The effects of these fate and transport processes on the dissolved groundwater plume will be investigated using the quantitative groundwater analytical data and solute-transport models. Data collection and analysis requirements are discussed in Section 3 of this work plan.

2.2.5 Potential Pathways and Receptors

2.2.5.1 Potential Pathways and Receptors at FTA 2

Precipitation runoff at FTA 2 flows to the storm sewer system. The groundwater at FTA 2 flows generally west-southwest. A light industrial area is present southwest of FTA 2. Some of the monitoring wells associated with FTA 2 are located in the industrial area (Figure 1.3). Because the site is located near an industrial area on a secured military Base, Base workers are the most probable potential receptors that could be exposed to any site-related contamination. Other receptors include Tinker AFB water supply wells located on the western portion of the Base.

2.2.5.2 Potential Pathways and Receptors at Area A

There are two Base water supply wells located approximately 1 mile west of Area A, but both of these wells are screened nearly 400 feet bgs in the confined regional

aquifer. The direction of shallow groundwater flow in the area of Area A is generally west-southwest.

Because the site is near recreational facilities for a secured military Base, Base workers and their families could be exposed to site-related contamination. Water supply well WS-32 is located to the northeast of the Area A Service Station, and is also a potential receptor.

SECTION 3

COLLECTION OF ADDITIONAL DATA

To complete the demonstration and to assess the degree to which RNA of BTEX and CAHs is occurring at Sites FTA 2 and Area A, additional site-specific physical and chemical hydrogeologic data will be collected to supplement the available site data. Many of these measurements and analyses are commonly performed at hazardous waste sites; however, some of the data will be collected specifically to assess the potential for use of RNA for the BTEX and CAHs at FTA 2 and Area A. The following information will be determined from the site investigation:

- Groundwater elevations at site monitoring wells;
- Mobile LNAPL composition, extent, and thickness (at Area A only);
- Concentration and extent of soil and groundwater contamination (analyses listed in Table 3.1);
- Subsurface geochemistry (analyses listed in Table 3.1);
- Locations of potential groundwater recharge and discharge areas;
- Locations of downgradient wells and their uses;
- Hydraulic conductivity through slug tests;
- Stratigraphy of subsurface media; and

TABLE 3.1
ANALYTICAL PROTOCOLS FOR
GROUNDWATER, FREE PRODUCT, AND SOIL SAMPLES
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

MATRIX Analyte	METHOD	FIELD (F) OR ANALYTICAL LABORATORY (L)
WATER		
Total Iron	Colorimetric, Hach Method 8008 (or similar)	F
Ferrous Iron (Fe^{+2})	Colorimetric, Hach Method 8146 (or similar)	F
Ferric Iron (Fe^{+3})	Difference between total and ferrous iron	F
Manganese	Colorimetric, Hach Method 8034 (or similar)	F
Sulfide	Colorimetric, Hach Method 8131 (or similar)	F
Sulfate	Colorimetric, Hach Method 8051 (or similar)	F
Nitrate	Titrimetric, Hach Method 8039 (or similar)	F
Nitrite	Titrimetric, Hach Method 8507 (or similar)	F
Redox Potential	A2580B, direct-reading meter	F
Oxygen	Direct-reading meter	F
pH	E150.1/SW9040, direct-reading meter	F
Conductivity	E120.1/SW9050, direct-reading meter	F
Temperature	E170.1, direct reading meter	F
Alkalinity (Carbonate [CO_3^{-2}] and Bicarbonate [HCO_3^{-1}])	Titrimetric, Hach Method 8221 (or similar)	F
Carbon Dioxide	Titrimetric, Hach Method 1436-01	F
Nitrate	E353.1	L
Nitrite	E353.1	L
Chloride	Waters Capillary Electrophoresis Method N-601	L
Sulfate	Waters Capillary Electrophoresis Method N-601	L
Alkalinity	E310.1	L
Methane, Ethane, Ethene	RSKSOP-147 ^{a/}	L
Dissolved Organic Carbon	RSKSOP-102	L
VOCs (BTEX, CAHs, chloroform, chloromethane)	RSKSOP-148	L
FREE PRODUCT		
Free Product (BTEX and CAHs)	GS/MS, Direct Injection SW8240B	L
SOIL		
Total Organic Carbon	RSKSOP-102 & RSKSOP-120	L
Moisture	ASTM D-2216	L
VOCs (BTEX + CAHs)	RSKSOP-124, modified	L

^{a/}RSKSOP = Robert S. Kerr Laboratory standard operating procedure.

- Locations of preferential groundwater migration pathways and receptor exposure points (if present).

In general, analyses will be performed to allow an inference of which biodegradation processes are ongoing, as well as to provide information useful for solute transport modeling. Some inorganic groundwater chemical parameters [e.g., ferrous iron, DO, or sulfate] are measured to evaluate if there is any ongoing degradation of native or anthropogenic carbon (e.g., BTEX). If such processes are ongoing, they may facilitate degradation of CAHs via the pathways discussed in Section 2.2.3. Chloride data can also be used as an indicator of dechlorination, which can result in increased chloride concentrations in CAH plume interiors. Carbon dioxide data may also indicate biodegradation, as it is the ultimate product of many of the biochemical reaction pathways. Oxidation/reduction potential (ORP) will be measured to help evaluate whether conditions are more suited for biologically mediated reductive dechlorination or oxidation reactions to occur, as well as an indicator parameter for well purging, along with DO, temperature, pH, and conductivity. Methane, ethane, and ethene will be measured for evidence of complete dechlorination of CAHs, while trends in BTEX and CAH concentrations over time can be used to further evaluate the ongoing processes.

Soil analyses will be performed primarily to gain information on the distribution and concentrations of organic carbon, which can aid in sorption or act as an electron donor. However, selected soil samples also will be analyzed for VOCs if field headspace measurements indicate the presence of significant concentrations of VOCs. Additional analyses not listed in Table 3.1 may be performed at the discretion of the Parsons ES, USACE, or USEPA NRMRL scientists working at the site. Additional analytes that may be tested for are listed in Appendix A.

If sufficient product thickness is encountered at Area A, samples of mobile LNAPL will be collected and analyzed for mass fraction of BTEX and CAHs.

Physical hydrogeologic parameters will be measured to further refine the site conceptual models and to aid in assembling and calibrating the groundwater flow portion of a site-specific transport model. To obtain these data, groundwater levels will be measured, and aquifer testing will be conducted. The following sections describe the procedures that will be followed when collecting additional site-specific data.

3.1 SITE MANAGEMENT

The following paragraphs outline site management issues pertaining to the field activities to be conducted at Sites FTA 2 and Area A. Base support, contingency plans, and waste management are discussed.

3.1.1 Base Support

The Base will provide the following support during field activities:

- **Provide Site Access to Field Team Members.** The Base point of contact (POC) will ensure daily access to the sites through arrangements with Tinker AFB security personnel.
- **Coordinate Badge and Vehicle Passes.** The Base POC will coordinate with Tinker AFB security personnel for the issue of personnel badges and vehicle passes for each field team member. Applicable forms will be completed by the Parsons ES field team members. Each field team member will be provided with a badge and vehicle pass (if needed).
- **Provide Flight-Line Drivers Training.** The Base POC will coordinate with Tinker AFB security personnel to provide flight-line drivers training necessary

for work at FTA 2. Each field team member will be provided with flight-line drivers training.

- **Provide Scheduling Information.** The Base POC will notify Parsons ES and USACE of any Base activities that may adversely affect field activities and/or impact the sampling schedule.
- **Provide Base Notification.** The Base POC should ensure that all pertinent parties (e.g., military police, Base Commander's Office) are notified in advance of the drilling and sampling activities.
- **Provide Water Hook-ups and a Central Decontamination Area.** The Base POC will arrange for access to a potable water supply at the site or on the Base for equipment decontamination. In addition, the Base will designate a convenient decontamination area for cleaning equipment. Non-hazardous water wastes from the decontamination area will be transported to a location specified by Base personnel for temporary storage pending coordination of discharge to the Base groundwater treatment plant (GWTP), industrial wastewater treatment plant (IWTP), or sanitary sewer.
- **Provide Access to Office Equipment.** Parsons ES will need access to a telephone with long distance capability and a copy machine to allow for efficient copying of chain-of-custody records and other field forms, as well as distribution of any memos pertaining to site coordination.
- **Assign Accumulation Points.** Any drilling cuttings, well purge fluids, and decontamination rinseate generated during site work that are suspected of being hazardous will be properly contained and moved to predesignated accumulation points for proper disposal.

- **Provide Underground Utility Clearance/Drilling Permits.** Before any work, each proposed intrusive sampling location must be checked for underground utilities by Base personnel or utility representatives, or both. The Base POC will ensure that the field team has written approval before drilling. A copy of clearances will be kept at the site where the drilling work will be conducted. Parsons ES will request clearance of locations at least 10 days before commencement of intrusive site work. The Base will issue digging or other appropriate permits prior to commencement of drilling operations.

3.1.2 Contingency Plans

This subsection describes steps that will be taken by Parsons ES to minimize delays during the investigations. Potential problems that could be encountered during the field effort include:

- Access and coordination difficulties;
- Equipment breakdowns;
- Conflicts with planned sampling locations;
- Abnormal site conditions (e.g., severe weather, unexpected Base operations); and/or
- Drilling permit delays.

3.1.2.1 Access and Coordination Contingencies

Anticipated support needs are outlined in Section 3.1.1. In the event that site access difficulties arise, the Base POC will be contacted to resolve the problem. The Base POC also will be notified if additional support needs arise during the field effort. The Parsons ES site manager and field team leader will be responsible for notifying the

Base POC and/or other designated personnel (e.g., designated site escorts/contacts) of access or coordination difficulties.

3.1.2.2 Equipment Contingencies

In the event of operation problems with field equipment or testing instruments, the following actions will be taken:

- Contact the field team leader;
- Refer to the instrument's instruction book for troubleshooting procedures; and
- Contact the manufacturer and/or supplier.

If necessary, backup instruments will be obtained. However, any such decisions will be made by the Parsons ES site manager after consideration of other potential solutions. Equipment will be maintained and extra batteries and other standard replacement will be carried in order to avoid downtime due to minor problems.

3.1.2.3 Sampling Location Contingencies

During the field effort, certain chosen sampling locations may be inaccessible due to site conditions. When the conditions can be adjusted (e.g., unlocking a gate or moving a vehicle), the Parsons ES site manager and/or field team leader, or USACE field team leader will contact the Base POC and/or site escort to arrange for access to the sampling location. When the sampling location remains inaccessible (e.g., due to overhead wires or underground cables), a new sampling location will be selected as close as possible to the originally designated location. If all areas in the vicinity of the sampling location are affected, the Parsons ES site manager or Parsons ES project manager will contact the Base POC to determine the next best nearby location, or revise the sampling strategy.

3.1.2.4 Abnormal Site Condition Contingencies

If abnormal site conditions are encountered that adversely affect site activities, the following actions will be taken:

- The Base POC will be notified of the conditions (e.g., mowing grass, unexpected construction).
- If the abnormal site conditions cannot be altered, an alternative sampling site will be selected.
- If the abnormal site conditions affect all sampling locations and/or if moving to another sampling site will adversely impact the project schedule or cost, both the Base POC and the AFCEE POC will be notified. A decision will then be made as to the best course of action to ensure quality project completion in a timely and cost-effective manner. Abnormal or unanticipated site conditions that adversely affect personnel health and safety are covered in the program Health and Safety Plan (Parsons ES, 1996).

3.1.2.5 Drilling Permit Delays

To ensure that drilling permits are issued prior to the planned drilling dates, the following Base procedure will be followed. Parsons ES personnel will identify drilling locations at the time of the kickoff meeting with pin flags, flagging tape, or fluorescent paint. A drawing indicating the locations and depths of the proposed drilling activities will be provided to the Base POC by Parsons ES at least 10 days prior to sampling activities. Civil Engineering and/or utility personnel will locate underground utility lines and buried structures that might be affected by any drilling prior to mobilization. No drilling will be allowed until the permit is approved by all parties. The drilling permit will be effective only for the time period indicated by the final signature authority. Reauthorization from all organizations and the technical representative shall

be required for any additional time required after expiration of the original permit period.

3.1.2.6 Site Health and Safety Plan

Parsons ES will provide a Health and Safety Plan (Parsons ES, 1996) and a site-specific addendum for field investigations to be conducted at Tinker AFB. The documents will be provided to the Base POC for review prior to field mobilization, if requested by the Base POC. The plan includes the following information:

- An index of all hazardous materials to be introduced to the site;
- Plan for protecting personnel and property during the transport, storage and use of the materials;
- Procedures for spill response and disposal;
- Material safety data sheets (MSDSs) for materials listed in the index of the plan; and
- Approved labeling system to identify contents on all containers on site.

3.1.3 Site Restoration and Waste Handling

After drilling activities are complete, each sampling location will be restored as closely to its original condition as possible. Soils generated during site investigation activities at FTA 2 and Area A may potentially contain a listed hazardous waste. These soils will be visually examined and field screened for VOCs with an organic vapor meter (OVM). If soils are not visually contaminated and have a headspace reading of less than 5 parts per million, volume per volume (ppmv), then the soil will be contained and staged at assigned accumulation points for appropriate disposal as nonhazardous waste. Otherwise, the soil will be containerized, and transported to a central staging area pending receipt of groundwater quality data from the installed

monitoring points or wells. If the groundwater samples do not contain VOC concentrations in excess of the toxicity characteristics leaching procedure (TCLP) criteria, then the soils will be disposed of with nonhazardous soils as directed by Base personnel. If the VOC concentrations in groundwater exceed TCLP criteria; then the soils will be sampled for analysis of RCRA hazardous waste characteristics (ignitability, corrosivity, reactivity, and toxicity). If applicable hazardous waste criteria are exceeded, then the soil will be disposed of as a hazardous waste at an appropriate offsite facility by USACE.

Groundwater removed from monitoring wells during development or purging, used for decontamination, or generated from drilling activities, will be temporarily contained and transported to assigned accumulation points. Water will be contained in large capacity storage tanks to allow settling of solids, if necessary. The water will then be disposed of by Parsons ES or the USACE to the Base GWTP. If the water cannot be accepted by the Base GWTP, the water will be disposed of by the Base using another acceptable means (e.g., the Base IWTP, or a licensed contractor will transport the wastewater to a treatment and/or disposal facility).

Precautions will be taken to prevent spills of hazardous material. In the event of a spill, the Base POC will be notified immediately. Spill response will be in accordance with Title 40 of the Code of Federal Regulations, Part 300 (40 CFR 300) and applicable state regulations.

3.2 MONITORING POINT/WELL DRILLING, SOIL SAMPLING, AND INSTALLATION

To further characterize site hydrogeologic conditions and groundwater chemistry, an estimated total of up to 17 groundwater monitoring points or wells, and 5 optional monitoring points or wells, will be installed within and adjacent to FTA 2 and Area A CAH or BTEX plumes to supplement previously installed site monitoring wells. Small-diameter [0.05-inch inside diameter (ID), polyvinyl chloride (PVC)] monitoring

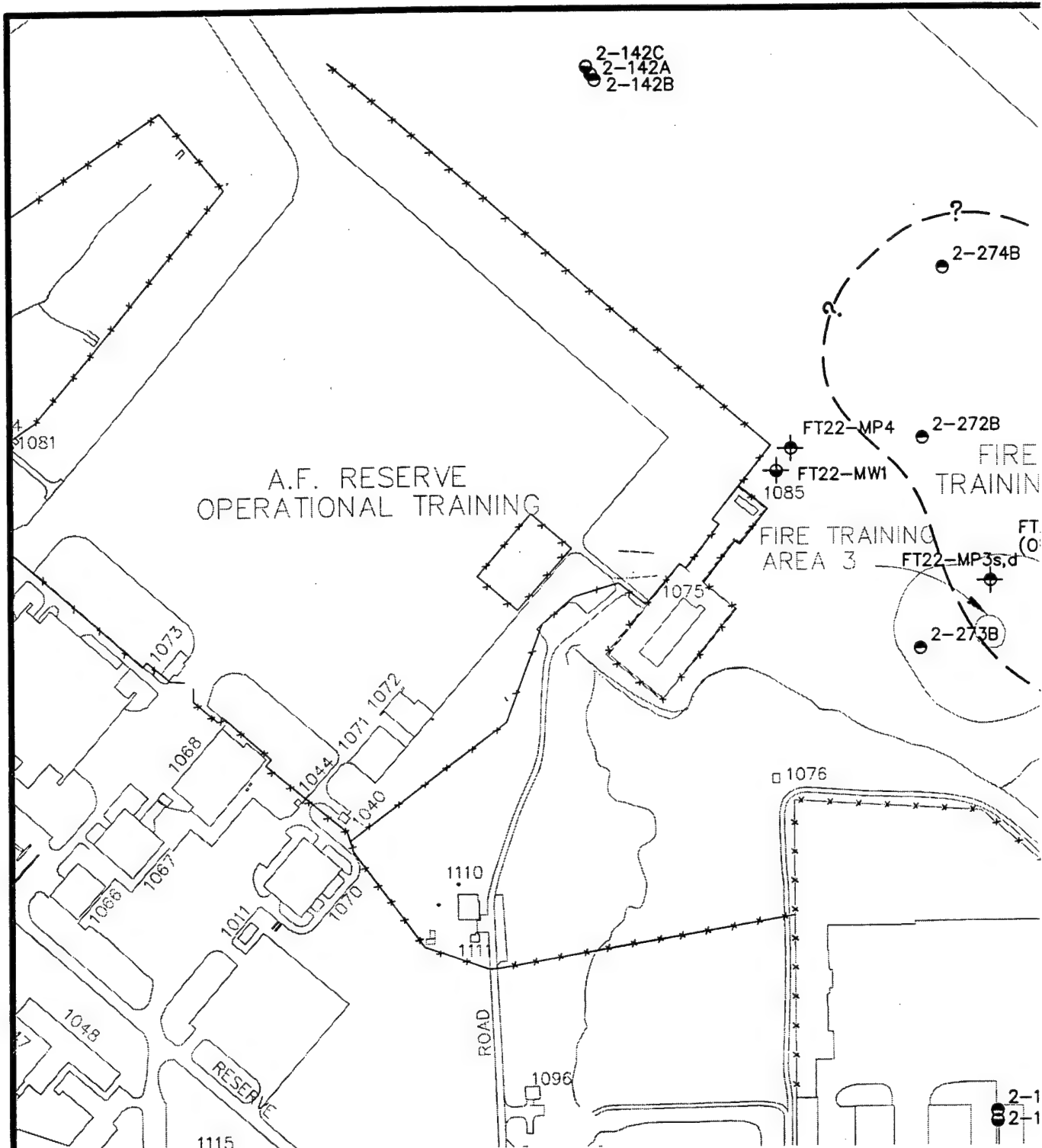
points will be installed using a Geoprobe® or hollow-stem auger (HSA) in the USZ where the groundwater is sufficiently near the ground surface (within approximately 25 feet) to allow use of a peristaltic pump to perform purging and sampling activities. Two-inch inside-diameter (ID) monitoring points will be installed using a HSA in the USZ where the depth to groundwater is deeper than approximately 25 feet. Double-cased, two or four-inch inside-diameter (ID) monitoring wells will be installed in the LSZ using wet-rotary drilling.

Monitoring points and wells will be installed by the USACE. The following sections describe the proposed monitoring point and well locations and completion intervals. Monitoring point and well installation, development, and decontamination will be performed in accordance with Tinker AFB well installation standards (Appendix D), as applicable. The following sections summarize the general monitoring point and well installation and development, as well as equipment decontamination, procedures.

3.2.1 Monitoring Point and Well Locations and Completion Intervals

3.2.1.1 FTA 2 Monitoring Point and Well Locations and Completion Intervals

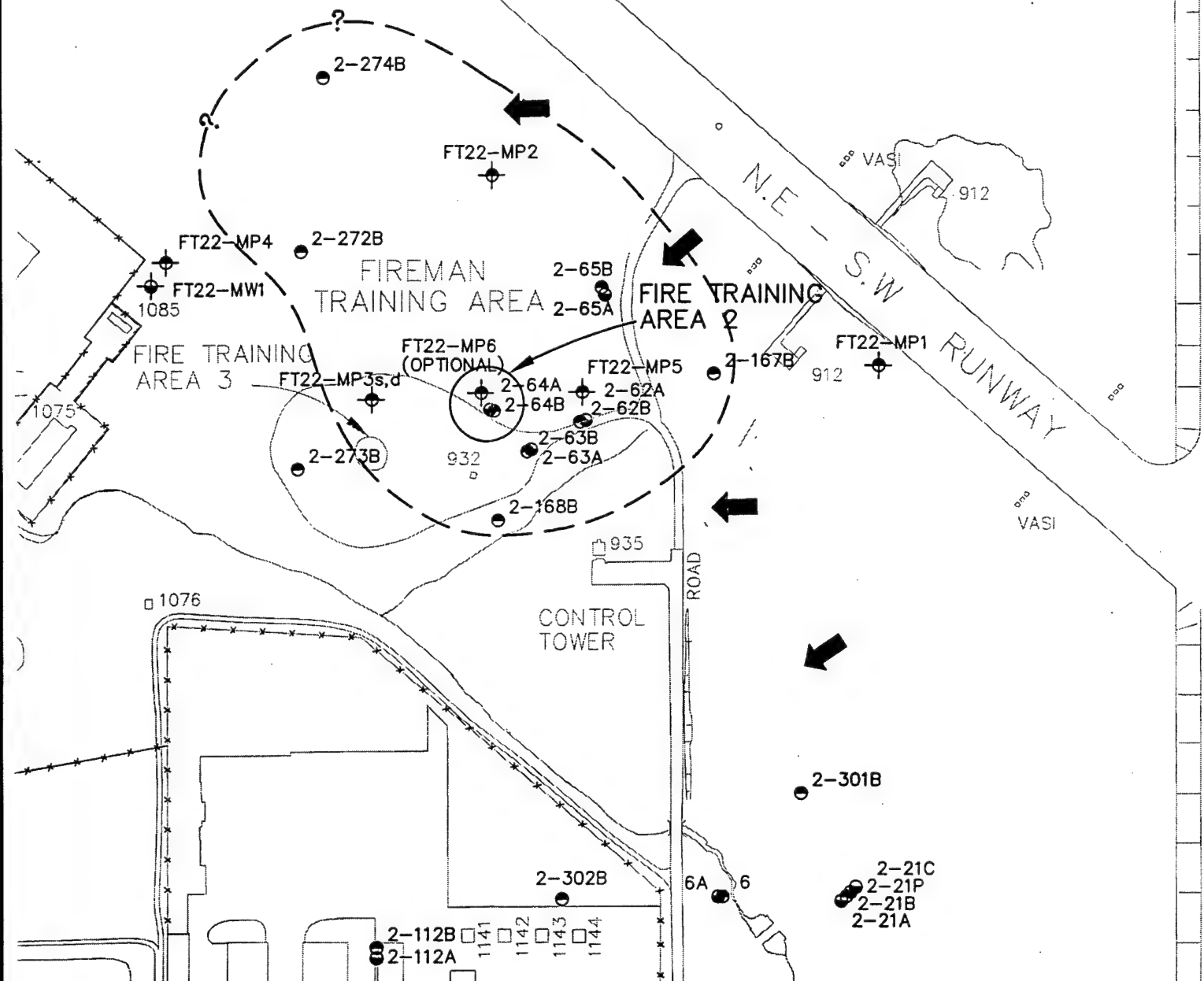
The locations of the proposed 7 groundwater monitoring points/wells, and 1 optional monitoring points for FTA 2 are identified on Figure 3.1. These locations were determined following a review of data gathered during previous site activities (IT, 1994 and Tinker AFB). Monitoring point/well locations were selected to provide hydrogeologic data necessary for successful implementation of a site-specific contaminant fate and transport model and to monitor potential chlorinated solvent migration from the site. Monitoring point/well locations were also selected to provide additional data on natural attenuation processes in the CAH plume. The 7 proposed locations shown on Figure 3.1 may be modified in the field as a result of conditions encountered in the field and acquired field data. The wells will be placed with the intent of verifying the downgradient plume extent and for collecting additional data




LEGEND

- | | | | |
|------------|---|------------|---------------------------------------|
| 2-142B ● | UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER | FT22-MW1 ⊕ | PROPOSED MONITORING LOWER SATURATED Z |
| 2-142A ● | LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER | s,d | SHALLOW AND DEEP POINT/WELL PAIR |
| FT22-MP1 ⊕ | PROPOSED MONITORING POINT/WELL LOCATION/ UPPER SATURATED ZONE | ← | DIRECTION OF USZ C |
| | | --- | APPROXIMATE EXTEN CAH PLUME |

2-271B



FT22-MW1  PROPOSED MONITORING WELL LOCATION/
LOWER SATURATED ZONE

s,d SHALLOW AND DEEP USZ MONITORING
POINT/WELL PAIR.

DIRECTION OF USZ GROUNDWATER FLOW

APPROXIMATE EXTENT OF USZ
CAH PLUME



②

FE

271B

1-67B
1-67A
1-67C

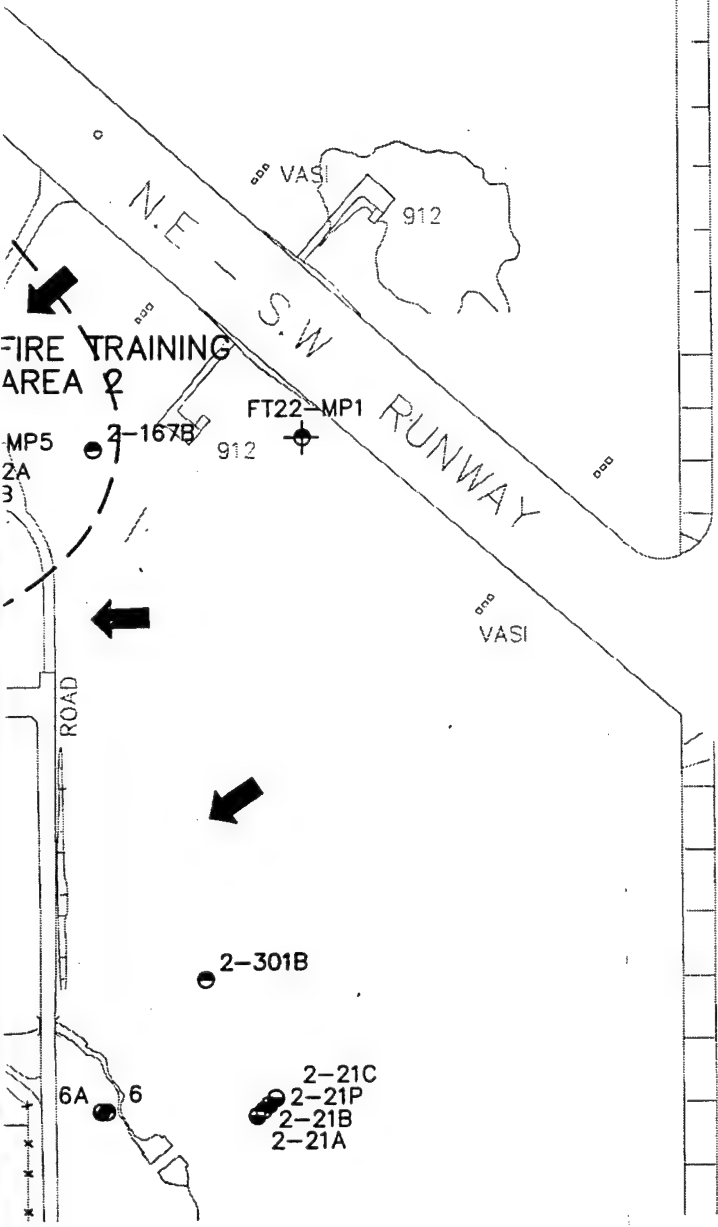
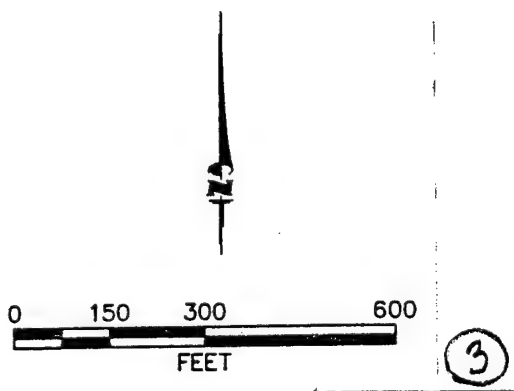


FIGURE 3.1
PROPOSED SAMPLING
LOCATIONS
FIRE TRAINING AREA 2

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado



within, up-, and cross-gradient from the plume. The rationale for the location of each of the proposed monitoring points/wells is provided in Table 3.2.

Monitoring points/wells may be installed singly, or in clusters of two points/well pairs. Single monitoring points/wells will be screened in the proper interval to detect maximum contaminant concentrations on the basis of data provided by IT (1994). Estimated screen intervals for all of the proposed monitoring points and wells are indicated in Table 3.2. These intervals may be altered in the field based on actual conditions encountered. Monitoring point/well clusters will be installed at locations where it is desirable to assess variations in groundwater chemistry with depth in the USZ, and to assess groundwater chemistry in the LSZ.

3.2.1.2 Area A Monitoring Well Locations and Completion Intervals

The locations of 10 proposed groundwater monitoring points/wells, and 4 optional monitoring points are identified on Figure 3.2. These locations were determined following a review of data gathered during previous site activities (IT, 1996). Monitoring point/well locations were selected to provide hydrogeologic data necessary for successful implementation of a site-specific contaminant fate and transport model and to monitor potential BTEX and CAH migration from the site. Monitoring well locations were also selected to provide additional data on natural attenuation processes in the BTEX and CAH plumes. The 10 proposed locations shown on Figure 3.2 may be modified in the field as a result of conditions encountered in the field and acquired field data. The wells will be placed with the intent of verifying the downgradient plume extent and for collecting additional data within, and up- and cross-gradient from the plumes. The rationale for the location of each of the proposed monitoring points/wells is provided in Table 3.3.

Monitoring wells may be installed singly, or in clusters of up to three points or wells. Single monitoring points will be screened in the proper interval to detect

TABLE 3.2
PROPOSED MONITORING WELL SUMMARY, FTA 2
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

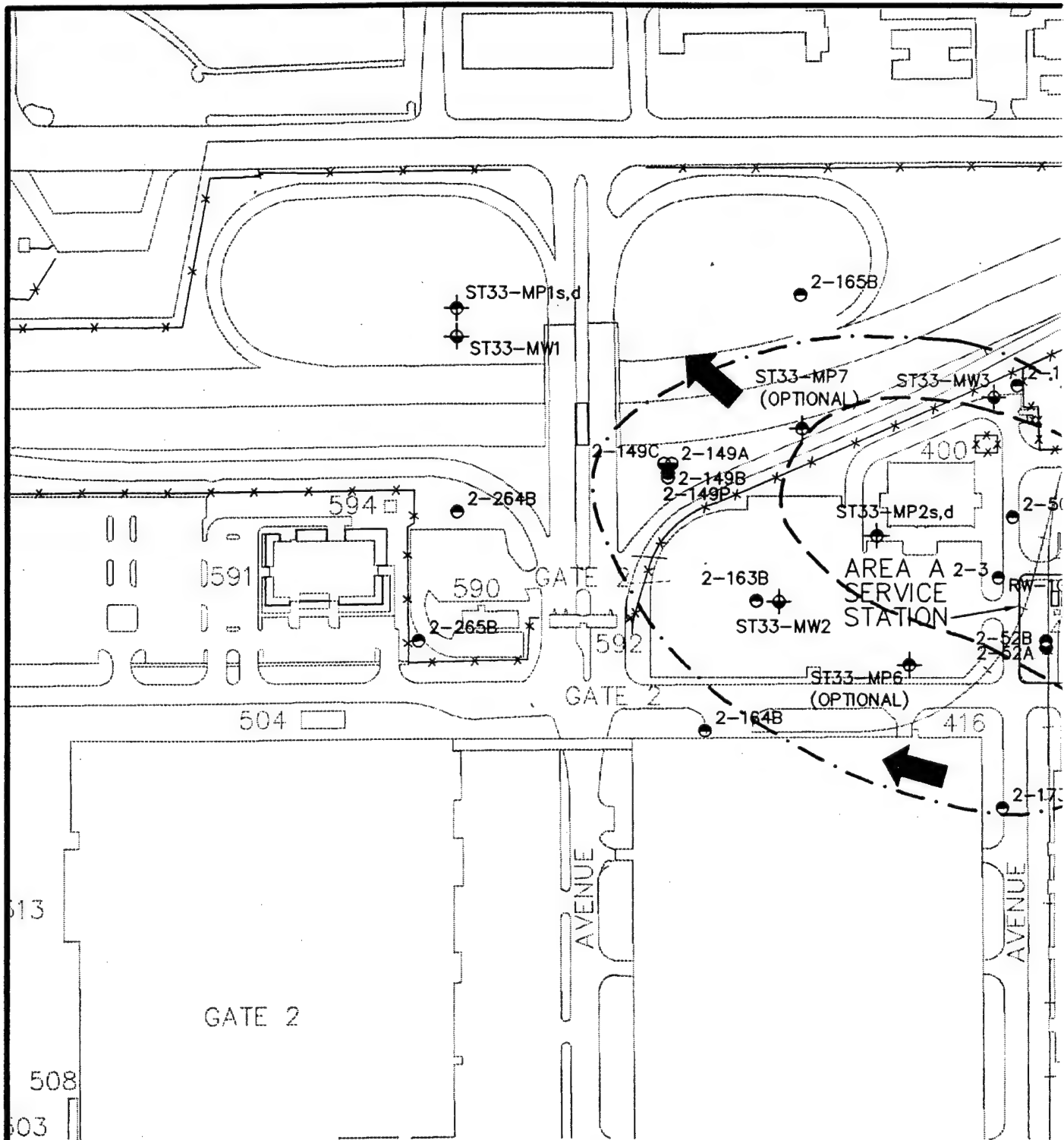
Well/Borehole Identification	Well I.D. ^{a/} (Inches)	Total Depth (Feet bgs) ^{b/}	Drilling Method ^{c/}	Screened Interval (Feet bgs)	Estimated Depth to Water (Feet bgs)	Screened Aquifer Zone ^{d/}	Plume Location	Rationale
New Monitoring Points (USZ)								
FT22-MP1	0.5 - 2.0	38'	Geoprobe/HSA	27-37'	16'	1st USZ Sand	Upgradient	Determine upgradient groundwater geochemistry, and CAH concentrations from potential offsite sources.
FT22-MP2	0.5 - 2.0	40'	Geoprobe/HSA	34-39'	13'	Base USZ	Lateral	Define USZ CAH plume extent to the south and collect cross-gradient geochemical data.
FT22-MP3	0.5 - 2.0	43'	Geoprobe/HSA	37-42'	16'	Base USZ	Lateral	Define USZ CAH plume to the north and apparent secondary CAH plume near well 2-274B. Collect cross-gradient geochemical data.
FT22-MP4s	0.5 - 2.0	26'	Geoprobe/HSA	20-25'	14'	1st USZ Sand	Plume Axis	Determine geochemistry and CAH concentrations in groundwater along plume axis.
FT22-MP4d	0.5 - 2.0	45'	Geoprobe/HSA	39-44'	14'	Base USZ	Plume Axis	Determine geochemistry and CAH concentrations in groundwater along plume axis.
FT22-MP5	0.5 - 2.0	45'	Geoprobe/HSA	39-44'	15'	Base USZ	Plume Axis/ Downgradient	Determine geochemistry and CAH concentrations in groundwater downgradient along the plume axis.
FT22-MP6 (optional)	0.5 - 2.0	45'	Geoprobe/HSA	39-44'	14'	Base USZ	Plume Axis	Pair well with 2-64B in the USZ to determine vertical groundwater geochemistry and CAH distributions.
FT22-MP7 (optional)	0.5 - 2.0	40'	Geoprobe/HSA	34-39'	14'	Base USZ	Plume Axis	Pair well with 2-62B in the USZ to determine vertical groundwater geochemistry and CAH distributions.
New Monitoring Wells (LSZ)								
FT22-MW1	2.0 - 4.0	83'	Wet Rotary	79-80'	55-60'	1st LSZ Sand	Downgradient	Determine if the USZ CAH plume infiltrates the LSZ in a downgradient direction.

^{a/} I.D. indicates well casing inside diameter.

^{b/} feet bgs indicates elevation in feet below ground surface.

^{c/} Drilling methods include Geoprobe direct-push, hollow-stem auger (HSA), and wet-rotary drilling techniques.

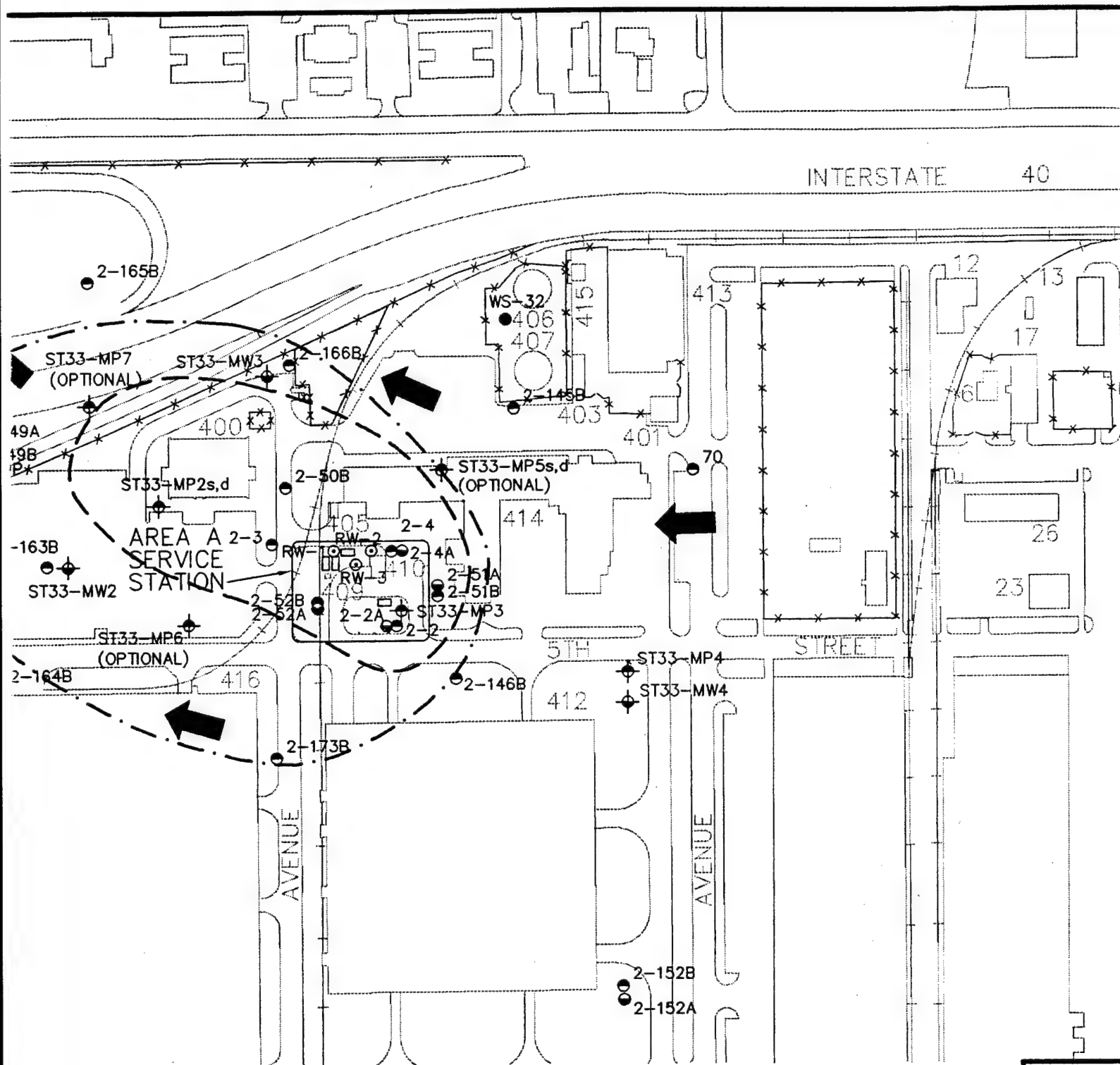
^{d/} Screened intervals include the upper-saturated zone (USZ) and the lower-saturated zone (LSZ).



LEGEND

- | | | | |
|----------|---|--------|--|
| ST33-MP1 | PROPOSED MONITORING POINT LOCATION/
UPPER SATURATED ZONE | 2-165B | UPPER SATURATED ZONE MON
LOCATION AND ID NUMBER |
| ST33-MW1 | PROPOSED MONITORING WELL LOCATION/
LOWER SATURATED ZONE | 2-2A | LOWER SATURATED ZONE MON
LOCATION AND ID NUMBER |
| s,d | SHALLOW AND DEEP USZ MONITORING
POINT PAIR | ← | DIRECTION OF USZ GROUNDWATER |
| WS-32 | WATER SUPPLY WELL | --- | APPROXIMATE EXTEND OF BTEX
IN USZ GROUNDWATER |
| | | - . - | APPROXIMATE EXTEND OF CAHs
IN USZ GROUNDWATER |





- B UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- A LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- DIRECTION OF USZ GROUNDWATER FLOW
- - - APPROXIMATE EXTEND OF BTEX IN USZ GROUNDWATER
- APPROXIMATE EXTEND OF CAHs IN USZ GROUNDWATER



2

PI

PARSC
ENGINE

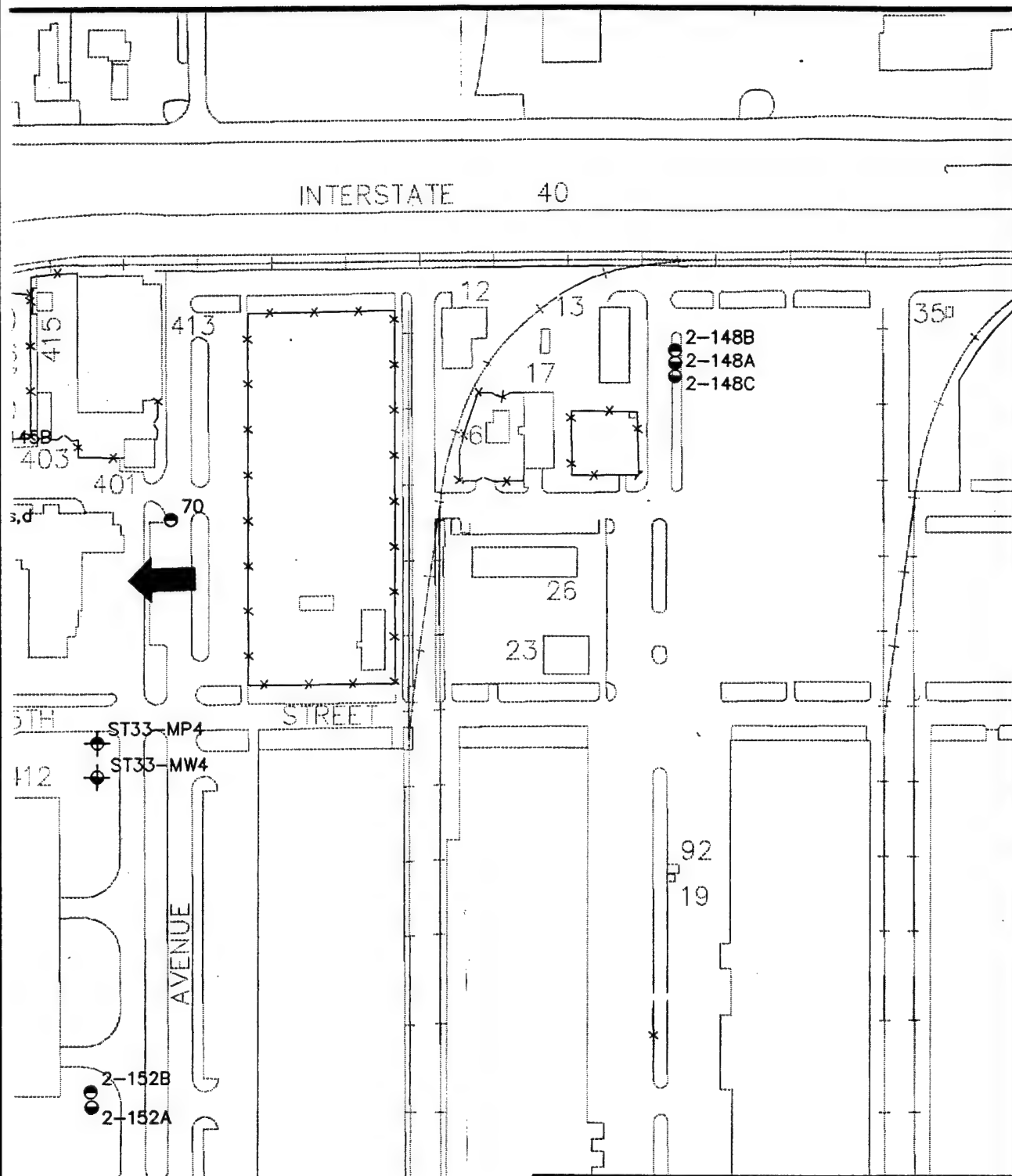


FIGURE 3.2

**PROPOSED SAMPLING
LOCATIONS
AREA A**

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

TABLE 3.3
PROPOSED MONITORING WELL SUMMARY, AREA A
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

Well/Borehole Identification	Well I.D. ^{a/} (Inches)	Total Depth (Feet bgs) ^{b/}	Drilling Method ^{c/}	Screened Interval (Feet bgs)	Estimated Depth to Water (Feet bgs)	Screened Aquifer Zone ^{d/}	Plume Location	Rationale
New Monitoring Points (USZ)								
ST33-MP1s	0.5 - 2.0	25'	Geoprobe/HSA	19-24'	20'	Water Table	Downgradient	Determine downgradient groundwater geochemistry and downgradient extent of USZ BTEX and CAH plumes.
ST33-MP1d	0.5 - 2.0	31'	Geoprobe/HSA	30-35'	20'	Base USZ	Downgradient	Pair point with MP1s in the USZ to determine vertical groundwater geochemistry, BTEX, and CAH distributions.
ST33-MP2s	0.5 - 2.0	21'	Geoprobe/HSA	15-20'	16'	Water Table	Plume Axis	Determine groundwater geochemistry, BTEX, and CAH concentrations along the plume axis.
ST33-MP2d	0.5 - 2.0	37'	Geoprobe/HSA	31-36'	16'	Base USZ	Plume Axis	Pair point with MP2s in the USZ to determine vertical groundwater geochemistry, BTEX, and CAH distributions.
ST33-MP3	0.5 - 2.0	37'	Geoprobe/HSA	31-36'	13-15'	Base USZ	Plume Axis	Pair point with 2-2 in the USZ to determine vertical (base USZ) groundwater geochemistry, BTEX, and CAH distributions.
ST33-MP4	0.5 - 2.0	36'	Geoprobe/HSA	25-35'	10'	Mid USZ Sand	Upgradient	Determine upgradient groundwater geochemistry, and CAH concentrations from potential offsite sources.
ST33-MP5s (optional)	0.5 - 2.0	20'	Geoprobe/HSA	14-19'	15'	Water Table	Lateral	Determine cross-gradient groundwater geochemistry and lateral extent of USZ BTEX and CAH plumes.
ST33-MP5d (optional)	0.5 - 2.0	36'	Geoprobe/HSA	30-35'	15'	Base USZ	Lateral	Pair point with MP5s in the USZ to determine vertical groundwater geochemistry, BTEX, and CAH distributions.
ST33-MP6 (optional)	0.5 - 2.0	36'	Geoprobe/HSA	30-35'	13'	Base USZ	Lateral	Determine groundwater geochemistry, BTEX, and CAH concentrations lateral to USZ BTEX and CAH plumes.
ST33-MP7 (optional)	0.5 - 2.0	36'	Geoprobe/HSA	30-35'	10'	Base USZ	Lateral	Determine groundwater geochemistry, BTEX, and CAH concentrations lateral to USZ BTEX and CAH plumes.
New Monitoring Wells (LSZ)								
ST33-MW1	2.0 - 4.0	55'	Wet Rotary	42-52'	45'	1st LSZ Sand	Downgradient	Determine downgradient groundwater geochemistry and downgradient extent of LSZ CAH plume.
ST33-MW2	2.0 - 4.0	60'	Wet Rotary	47-57'	45'	1st LSZ Sand	Lateral	Determine cross-gradient groundwater geochemistry and CAH concentrations lateral to LSZ CAH plume.
ST33-MW3	2.0 - 4.0	75'	Wet Rotary	62-72'	45'	2nd LSZ Sand	Lateral	Determine cross-gradient groundwater geochemistry and CAH concentrations lateral to LSZ CAH plume.
ST33-MW4	2.0 - 4.0	73'	Wet Rotary	60-70'	45'	2nd LSZ Sand	Upgradient	Determine upgradient groundwater geochemistry, and CAH concentrations from potential offsite sources.

a/ I.D. indicates well casing inside-diameter.

b/ feet bgs indicates elevation in feet below ground surface.

c/ Drilling methods include Geoprobe direct-push, hollow-stem auger (HSA), and wet rotary drilling techniques.

d/ Screened intervals include the upper-saturated zone (USZ) and the lower-saturated zone (LSZ).

maximum contaminant concentrations on the basis of data provided by IT (1996). Estimated screen intervals for all of the proposed monitoring wells and points are indicated in Table 3.3. These intervals may be altered in the field based on actual conditions encountered. Monitoring point clusters will be installed at locations where it is desirable to assess variations in groundwater chemistry with depth in the USZ, and to assess groundwater chemistry in the LSZ.

3.2.2 Monitoring Point and Well Advancement and Installation Procedures

Monitoring points will be advanced using a truck-mounted Geoprobe® or a drilling rig equipped with 4.25-inch-ID HSAs in the USZ, and monitoring wells will be advanced using a wet-rotary drilling rig in the LSZ. USACE will be responsible for all drilling, sampling, development, drilling waste disposal, and completion activities. All drilling and completion activities will be performed in accordance with Tinker AFB well installation standards (Appendix D).

A USACE field scientist will be responsible for observing all monitoring point/well field investigation activities, maintaining a detailed descriptive log of all subsurface materials recovered during soil coring, photographing representative samples, and properly labeling and storing samples. During borehole advancement, soil samples for visual description will be collected at a frequency sufficient to identify the depths of significant stratigraphic contacts (e.g., contacts between fill material and alluvium, between alluvium and bedrock, and between bedrock stratigraphic units). Sampling intervals will be determined on the basis of Tinker AFB well installation requirements. Soil samples will be obtained using a Geoprobe® soil drive sampler, a split-spoon sampling device, a continuous California sampler, or another similar method judged to be acceptable by the USACE field scientist. An example geologic borehole log form is presented in Figure 3.3. The descriptive log will contain data items listed in the Tinker AFB well installation standard (Appendix D), including the following:

GEOLOGIC BORING LOG

JOB NUMBER: _____	CLIENT: _____	DATE SPUD: _____
BORING NUMBER: _____	BORING DIA.: _____	DATE CMPL: _____
RIG TYPE: _____	CONTRACTOR: _____	ELEVATION: _____
TEMPERATURE (*F): _____	WEATHER: _____	DATUM: _____
LOCATION: _____	DRLG MED: _____	GEOLOGIST: _____
COMMENTS: _____		

Depth (ft.)	Pro- file	USCS	Geologic Description	Sample Interval	Laboratory Sample Identification	Sample Type	PID ppmv	Remarks
1								
5								
10								
15								
20								
25								
30								

NOTES:

BGS - Below Ground Surface	SS - Split Spoon Sample
NS - Not Sampled	G - Grab Sample
TOC - Top of Casing	D - Drive Sample
PID - Photoionization Detector	
ppmv - Parts per Million, Volume per Volume	

PARSONS ENGINEERING SCIENCE, INC.

FIGURE 3.3

GEOLOGIC BORING LOG

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

- Sample interval (top and bottom depth);
- Sample recovery;
- Presence or absence of contamination [as indicated by photoionization detection (PID) readings];
- Lithologic description, including relative density, color, major textural constituents, minor constituents, relative moisture content, plasticity of fines, cohesiveness, grain size, structure or stratification, and any other significant observations; and
- Depths of lithologic contacts and/or significant textural changes measured and recorded to the nearest 0.1 foot.

Monitoring well installation and completion materials will be inspected by the field scientist and determined to be clean and acceptable prior to use. If not factory sealed, the well points, casing, and tubing will be cleaned prior to use with a high-pressure, steam/hot-water cleaner using approved water. Materials that cannot be cleaned to the satisfaction of the field scientist will not be used. The field scientist will verify and record the borehole depth, the lengths of all casing sections, and the depth to the top of all well completion materials placed in the annulus between the casing and the borehole wall. All lengths and depths will be measures to the nearest 0.1 foot. Specific materials to be used for construction of USZ and LSZ wells are described in the following subsections.

3.2.2.1 USZ Monitoring Points/Wells

If subsurface conditions permit, monitoring points will be constructed of 0.75-inch outside-diameter (OD)/0.5-inch-ID PVC casing and well screen to provide additional water level and water quality data. Approximately 5 feet of factory-slotted screen will be installed for each shallow monitoring point. Effective installation of the shallow

monitoring points requires that the boreholes remain temporarily open upon completion of Geoprobe® penetration. Shallow 0.5-inch-ID PVC monitoring points will be installed by punching and sampling a borehole with the Geoprobe®. Upon removing the rods, the borehole depth will be measured to determine if the hole remains open. If the borehole is open, the 0.5-inch-ID PVC casing and screen will be placed at the appropriate depths. The annular space around the screen will be filled with sand filter pack, and the annulus around the casing will be filled with grout or bentonite. Monitoring point construction details will be noted on a Monitoring Point Construction diagram (Figure 3.4). This information will become part of the permanent field record for the site.

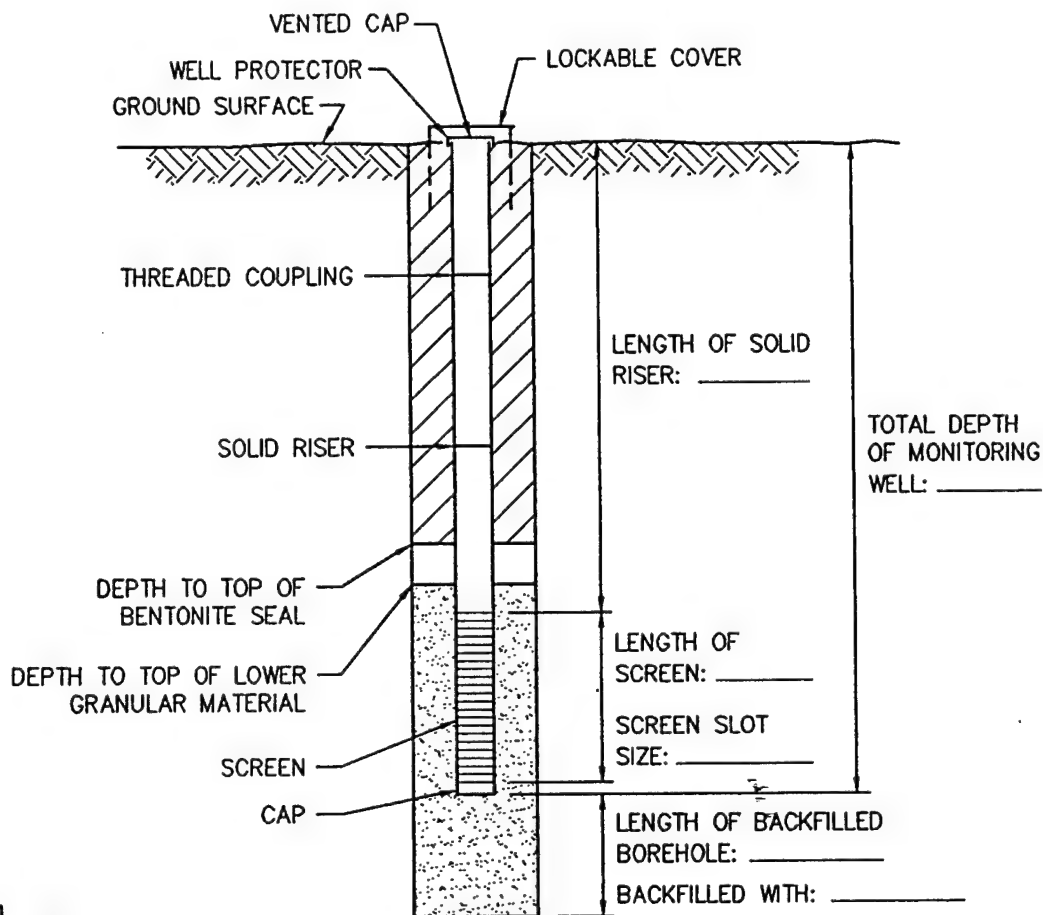
Monitoring point screens will be constructed of flush-threaded, Schedule 40 PVC with an ID of 0.5 inch. The screens will be factory slotted with 0.01-inch openings. Placement depth for monitoring point screens is described in Tables 3.2 and 3.3, along with the rationale for the selection of this depth. Blank monitoring point casing will be constructed of Schedule 40 PVC with an ID of 0.5 inch. All monitoring point casing sections will be flush-threaded; joints will not be glued. The casing at each monitoring point will be fitted with a bottom cap and a top cap constructed of PVC. If 0.5-inch PVC monitoring points cannot be installed, or the depth to water is greater than 25 feet, 2.0-inch ID PVC monitoring points be installed using a HSA drill rig. Screen slot size for 2.0-inch PVC monitoring points will be 0.10 inch, with a screen length of 10 feet.

3.2.2.2 LSZ Monitoring Wells




Double-cased monitoring well construction details will be noted on a Monitoring Well Construction diagram (Figure 3.5). LSZ monitoring wells will be drilled, sampled, and installed by the USACE, under supervision of a qualified USACE field scientist. LSZ monitoring well installation, development, and decontamination will be performed in accordance with Tinker AFB well installation standards (Appendix D).

SINGLE-CASED MONITORING POINT INSTALLATION RECORD

JOB NAME TINKER AIR FORCE BASE WELL NUMBER _____
 JOB NUMBER 729691 INSTALLATION DATE _____ LOCATION _____
 DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
 DATUM FOR WATER LEVEL MEASUREMENT _____
 SCREEN DIAMETER & MATERIAL _____ SLOT SIZE _____
 RISER DIAMETER & MATERIAL _____ BOREHOLE DIAMETER _____
 GRANULAR BACKFILL MATERIAL _____ ES REPRESENTATIVE _____
 DRILLING METHOD GEOPROBE/HOLLOW STEM AUGER DRILLING CONTRACTOR _____



(NOT TO SCALE)

-  GROUT
-  BENTONITE
-  GRANULAR BACKFILL

STABILIZED WATER LEVEL _____ FEET
 BELOW DATUM.
 MEASURED ON _____

FIGURE 3.4

SINGLE-CASED MONITORING POINT INSTALLATION RECORD

Sites FTA 2 and Area A
 RNA TS
 Tinker AFB, Oklahoma

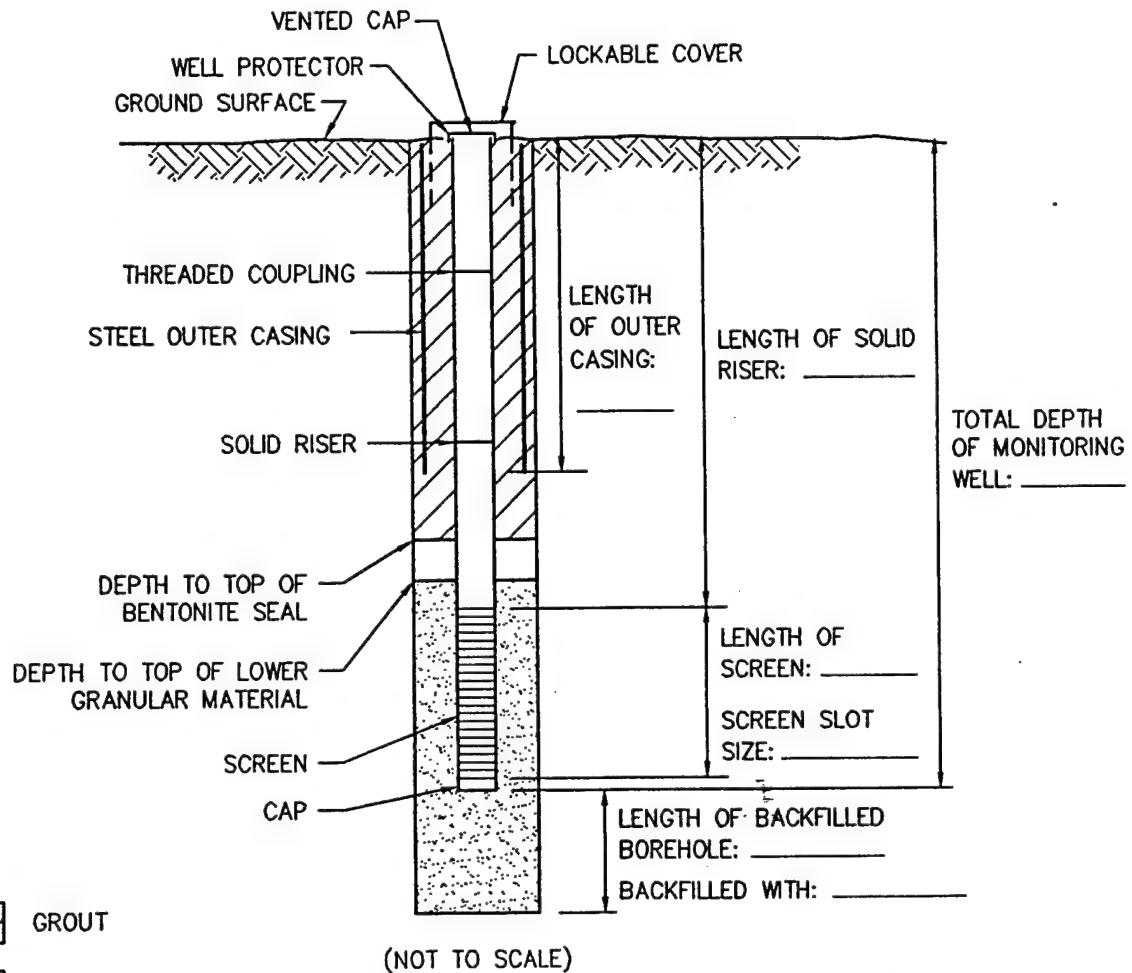


**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

DOUBLE-CASED MONITORING WELL INSTALLATION RECORD

JOB NAME TINKER AIR FORCE BASE WELL NUMBER _____
 JOB NUMBER 729691 INSTALLATION DATE _____ LOCATION _____
 DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
 DATUM FOR WATER LEVEL MEASUREMENT _____
 CASING DIAMETER & MATERIAL _____ BOREHOLE DIAMETER _____
 SCREEN DIAMETER & MATERIAL _____ SLOT SIZE _____
 RISER DIAMETER & MATERIAL _____ BOREHOLE DIAMETER _____
 GRANULAR BACKFILL MATERIAL _____ ES REPRESENTATIVE _____
 DRILLING METHOD WET-ROTARY DRILLING CONTRACTOR _____



STABILIZED WATER LEVEL _____ FEET
 BELOW DATUM.
 MEASURED ON _____

FIGURE 3.5 DOUBLE-CASED MONITORING WELL INSTALLATION RECORD

Sites FTA 2 and Area A
 RNA TS
 Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**
 Denver, Colorado

LSZ monitoring wells will be double-cased to the top of the USZ/LSZ aquitard. The outer casing will consist of a stainless steel casing keyed into the top of the hard silt/clay USZ aquitard. The casing ID will be a minimum of 8.5 inches in order to accommodate a borehole for installation of a 2- or 4-inch well surrounded by a minimum 2-inch annulus. The LSZ wells will be completed with 2- or 4-inch ID PVC screen and riser. Screens will be 15 feet long with a 0.10-inch slot size.

3.2.3 Collection of Soil Samples for Field Screening and Laboratory Analysis During Monitoring Well/Point Drilling

Soil samples will be collected at 5-foot intervals throughout the vadose zone during drilling of monitoring point/wells located in or near potential contamination source areas (Figures 3.1 and 3.2). A portion of each sample will be used to measure the total ionizable VOC concentration in soil headspace using a PID. Each headspace screening sample will be placed in a clean, sealed plastic bag or mason jar and allowed to equilibrate to the ambient temperature for at least 15 minutes. The PID probe will then be inserted into the bag or jar, and the maximum reading will be recorded in the field records. If headspace readings significantly above background readings are obtained, indicating the presence of vadose zone contamination, then the sample may be submitted to a laboratory for analysis of VOCs using the method specified in Table 3.1. Each laboratory soil sample will be placed in an analyte-appropriate sample container and hand-delivered to the USEPA field laboratory personnel for analysis. If USEPA personnel have not mobilized to the site, then the samples will be shipped on ice to the NRMRL via overnight courier.

Soil samples for TOC analysis will also be collected from selected monitoring well/point boreholes located in uncontaminated or minimally contaminated areas cross-gradient or downgradient from the CAH plume. One sample for TOC analysis will be collected from each major lithologic unit encountered in the saturated zone during

advancement of monitoring point/wells from a minimum of one upgradient location at each site.

3.2.4 Equipment Decontamination During Drilling and Soil Sampling Activities

Prior to arriving at the site, and between each sampling location, probe rods, tips, sleeves, pushrods, augers, drill rods, drill bits, samplers, tools, and other downhole equipment will be decontaminated using a high-pressure, steam/hot water wash. Only potable water will be used for decontamination.

When collecting soil samples for laboratory analysis of VOCs, the sampling device will be disassembled and decontaminated with Alconox[®] and potable water between each soil sample. Sampling barrels will then be rinsed with deionized water and a solvent (methanol or isopropanol), air-dried, and reassembled with new liners, if applicable. Between uses, the sampling equipment will be wrapped in clean plastic or foil to prevent contamination. Prior to collection of samples for TOC analysis, the sampling device will be rinsed with potable water and scrubbed with a stiff brush, as necessary, to remove soil particles from previous sampling intervals.

All rinseate will be collected for transportation and proper disposal with decontamination and development waters (Section 3.1.3). Alternate methods of rinseate disposal will be considered by the Parsons ES or USACE field scientist as recommended by Base personnel. Precautions will be taken to minimize any impact to the surrounding area that might result from decontamination operations.

3.2.5 Monitoring Point Development and Records

The newly installed monitoring points and wells will be developed prior to sampling to remove fine sediments and introduced fluids from the portion of the formation adjacent to the screened interval. Development of 0.5-inch ID PVC monitoring points will be accomplished using a peristaltic pump provided by USEPA NRMRL or Parsons

ES. Development of larger diameter monitoring points/wells will be accomplished using an electric submersible pump and, if necessary to obtain acceptable water clarity, a surging device. Monitoring point development will occur a minimum of 24 hours prior to sampling, and monitoring well development will occur a minimum of 72 hours prior to sampling.

Development will continue until a minimum of 5 times the standing water volume in the monitoring point/well (to include the well screen and casing plus saturated annulus, assuming 30-percent porosity) have been removed, and the water pH, temperature, and specific conductance have stabilized. Monitoring wells installed using wet-rotary drilling methods will develop an additional 5 times the measured amount of total fluids lost while drilling. If the development water is still turbid after removal of the minimum number of casing volumes, development will continue until the water becomes clear or the turbidity of the water produced has been stable after the removal of several additional casing volumes. In low-yield wells that go dry during development, development activity will be staged over a period of time to allow water to refill the well bore. In the event that the minimum number of casing volumes cannot be removed, the water volume recovered and the deficiency will be noted in the development records.

A development record will be maintained for each monitoring point and well. The development record will be completed in the field by the field scientist. Figure 3.6 is an example of a development record used for similar well installations. Development records will include at a minimum:

- Monitoring point/well number;
- Date and time of development;
- Development method;

Job Number: 729691.34020
Location: Tinker AFB FTA 2 / Area A
Well/Point ID: _____

Job Name: AFCEE-RNA
Developed by: _____ Date: _____
Measurement Datum: _____

Pre-Development Information

Time (Start): _____

Water Level: _____

Total Depth of Well: _____

Initial Water Characteristics

Color _____ Clear Slightly Cloudy Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature(°C) _____
Specific Conductance(μS/cm) _____

Interim Water Characteristics

Time: _____

Gallons Removed _____

pH _____

Temperature (°C) _____

Specific Conductance (μS/cm) _____

Post-Development Information

Time (Finish): _____

Water Level: _____

Total Depth of Well: _____

Gallons Removed: _____

Water Characteristics

Color _____ Clear Slightly Cloudy Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature(°C) _____
Specific Conductance(μS/cm) _____

Comments:

FIGURE 3.6

**MONITORING WELL
DEVELOPMENT RECORD**

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

- Monitoring point/well depth;
- Volume of water produced;
- Description of water produced;
- Post-development water level and monitoring point depth; and
- Field analytical measurements, including pH and specific conductivity.

Development waters will be collected and held for proper disposal to the Base GWTP. Alternate methods of water disposal will be considered by the USACE field scientist as recommended by Base personnel.

3.2.6 Datum Survey

The horizontal location of all soil sampling locations relative to established Base coordinates will be measured by a surveyor. Horizontal coordinates will be measured to the nearest 0.5 foot using a State Plane Lambert Coordinate System. Coordinates shall be reported in feet or meters using the 1983 North American Datum, Oklahoma North Zone; and in feet using the 1927 North American Datum, Oklahoma North Zone. The elevation of the ground surface and the top of well casings will also be measured to the nearest 0.01 foot using the NGVD of 1929.

3.3 GROUNDWATER SAMPLING PROCEDURES

This section describes the procedures for collection of groundwater quality samples. Groundwater samples will be collected from selected previously installed monitoring wells, and from all newly installed groundwater monitoring wells. Figures 3.1 and 3.2 show the locations of monitoring wells from which groundwater samples will be collected at FTA 2 and Area A, respectively. In order to maintain a high degree of QC during this sampling event, the procedures described in the following sections will be followed.

3.3.1 Groundwater Sampling Strategy

Groundwater samples will be collected from previously installed monitoring wells and from monitoring points/wells installed during this project (Figures 3.1 and 3.2). At FTA 2, the existing wells to be sampled will include 2-62B, 2-63B, 2-64B, 2-65B, 2-167B, 2-168B, 2-271B, 2-272-B, 2-273B, and 2-274B in the USZ; and 2-62A, 2-63A, 2-64A, and 2-65A in the LSZ. At Area A, the existing wells to be sampled will include 2-2, 2-3, 2-4, 2-50B, 2-51B, 2-52B, 2-145B, 2-146B, 2-149B, 2-163B, 2-164B, 2-165B, 2-166B, 2-173B, 2-264B, 2-265B, and 70 in the USZ; and 2-2A, 2-4A, 2-51A, 2-52A, and 2-149A in the LSZ. In addition, all newly installed monitoring points/wells at both sites will be sampled.

Sampling will be conducted by qualified scientists and technicians from Parsons ES and the USEPA NRMRL who are trained in the performance of groundwater sampling, records documentation, and chain-of-custody procedures. In addition, sampling personnel will have thoroughly reviewed this work plan prior to sample acquisition and will have a copy of the work plan available onsite for reference.

3.3.2 Preparation for Sampling

All equipment to be used for sampling will be assembled and properly cleaned and calibrated (if required) prior to arriving in the field. In addition, all record-keeping materials will be gathered prior to leaving the office.

3.3.2.1 Equipment Cleaning

All portions of sampling and test equipment that will contact the sample matrix will be thoroughly cleaned before each use. This includes split spoon samplers, water level probe and cable, test equipment for onsite use, and other equipment or portions thereof that will contact the samples. Based on the types of sample analyses to be conducted, the following cleaning protocol will be used:

- Wash with potable water and phosphate-free laboratory detergent (HP-II detergent solutions, as appropriate);
- Rinse with potable water;
- Rinse with isopropyl alcohol;
- Rinse with distilled or deionized water; and
- Air dry the equipment prior to use.

Any deviations from these procedures will be documented in the field scientist's field notebook and on the Groundwater Sampling Record (Figure 3.7).

If precleaned disposable sampling equipment is used, the cleaning protocol specified above will not be required. Laboratory-supplied sample containers will be cleaned and sealed by the laboratory. The type of container provided and the method of container decontamination will be documented in the laboratory's permanent record of the sampling event.

3.3.2.2 Equipment Calibration

As required, field analytical equipment will be calibrated according to the manufacturers' specifications prior to field use. This applies to equipment used for onsite measurements of DO, pH, electrical conductivity, alkalinity, redox potential, sulfate, nitrate, ferrous iron (Fe^{2+}), and other field parameters listed in Table 3.1.

3.3.3 Well and Monitoring Point Sampling Procedures

Special care will be taken to prevent contamination of the groundwater and extracted samples. The primary way in which sample contamination can occur is through cross-contamination due to insufficient cleaning of equipment between wells and monitoring points. To prevent such contamination, the water level probe and cable used to

Sampling Location: Tinker AFB FTA 2 / Area A

Sampling Dates: _____

GROUNDWATER SAMPLING RECORD - MONITORING WELL _____

(number)

REASON FOR SAMPLING: ☐ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: _____ at _____ a.m./p.m.

SAMPLE COLLECTED BY: _____ of Parsons ES

WEATHER: _____

DATUM FOR WATER DEPTH MEASUREMENT (Describe): _____

MONITORING WELL CONDITION:

☐ LOCKED:

☐ UNLOCKED

WELL NUMBER (IS - IS NOT) APPARENT

STEEL CASING CONDITION IS: _____

INNER PVC CASING CONDITION IS: _____

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off

1 ☐ EQUIPMENT CLEANED BEFORE USE WITH _____
Items Cleaned (List): _____

2 ☐ PRODUCT DEPTH _____ FT. BELOW DATUM
Measured with: _____

WATER DEPTH _____ FT. BELOW DATUM
Measured with: _____

3 ☐ WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: _____
Turbidity: _____
Odor: _____
Other Comments: _____

4 ☐ WELL EVACUATION:
Method: _____
Volume Removed: _____
Observations: Turbidity (clear slightly cloudy very cloudy)
Water level (rose fell no change)
Water odors: _____
Other comments: _____

FIGURE 3.7

**GROUNDWATER
SAMPLING RECORD**

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

Monitoring Well No. _____ (Cont'd)

5 [] SAMPLE EXTRACTION METHOD:

- [] Bailer made of: _____
[] Pump, type: _____
[] Other, describe: _____

Sample obtained is [X] GRAB; [] COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Time						Measured with
Temp (°C)						
pH						
Cond (μ S/cm)						
DO (mg/L)						
Redox (mV)						
Salinity						

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

[] Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

[] Preservatives added:

Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [] CONTAINER HANDLING:

- [] Container Sides Labeled
[] Container Lids Taped
[] Containers Placed in Ice Chest

10 [] OTHER COMMENTS: _____

FIGURE 3.7(Cont.)

**GROUNDWATER
SAMPLING RECORD**

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

determine static water levels and total well depths will be thoroughly cleaned before and after field use and between uses at different sampling locations according to the procedures presented in Section 3.3.2.1. In addition to the use of properly cleaned equipment, dedicated high-density polyethylene (HDPE) tubing will be used at each monitoring point sampling location where a peristaltic pump is used for purging and sampling. Existing dedicated Grundfos® Redi-Flo II® pumps will be utilized for purging and sampling existing site monitoring wells. A properly decontaminated Grundfos® Redi-Flo II® or two-stage electric pump may be used for purging newly installed monitoring wells; a peristaltic pump with dedicated HDPE tubing or a disposable bailer will be used to sample these wells. A clean pair of new, disposable nitrile or latex gloves will be worn each time a different well or monitoring point is sampled. The following paragraphs present the procedures to be followed for groundwater sample collection from groundwater monitoring wells and monitoring points. These activities will be performed in the order presented below. Exceptions to this procedure will be noted in the sampler's field notebook and the groundwater sampling form.

3.3.3.1 Preparation of Location

Prior to starting the sampling procedure, the area around the existing wells and new monitoring points will be cleared of foreign materials, such as brush, rocks, and debris. These procedures will prevent sampling equipment from inadvertently contacting debris around the monitoring well/point. In addition, the sampling location will be inspected for the integrity of the protective cover, lock, external surface seal, concrete pad, cap, datum reference, and internal surface seal.

3.3.3.2 Water Level and Total Depth Measurements

Prior to removing any water from the monitoring well or monitoring point, the static water level will be measured. An electric water level probe (or oil/water interface probe) will be used to measure the depth to groundwater below the datum to the nearest

0.01 foot. After measuring the static water level, the water level probe will be slowly lowered to the bottom of the monitoring well/point, and the depth will be measured to the nearest 0.01 foot. Based on these measurements, the volume of water to be purged from the monitoring well/point will be calculated. If mobile LNAPL is encountered, the thickness of the LNAPL layer will be measured, and the total depth of the well/point will not be measured to minimize contamination of the water column with LNAPL.

3.3.3.3 Purging Before Sampling

The volume of water contained within the monitoring well/point casing at the time of sampling will be calculated, and three times the calculated volume will be removed from the well/monitoring point. Purge waters will be handled in accordance with the procedures outlined in Section 3.1.3.

If a monitoring well/monitoring point is evacuated to a dry state during purging, the monitoring well/monitoring point will be allowed to recharge, and the sample will be collected as soon as sufficient water is present in the monitoring well or monitoring point to obtain the necessary sample quantity. Sample compositing or sampling over a lengthy period by accumulating small volumes of water at different times to obtain a sample of sufficient volume will not be allowed.

3.3.3.4 Sample Extraction

HDPE tubing and a peristaltic pump will be used to extract groundwater samples from the monitoring well points. The tubing will be lowered through the well and 0.75-inch-OD PVC monitoring point casing into the water gently to prevent splashing. The sample will be transferred directly into the appropriate sample container. The water will be carefully poured down the inner walls of the sample bottle to minimize aeration of the sample. Existing dedicated Grundfos® Redi-Flo II® pumps will be

utilized for existing site monitoring wells. A peristaltic pump with dedicated HDPE tubing or disposable bailers may be used for newly installed monitoring wells.

Unless other instructions are given by the analytical laboratory, sample containers will be completely filled so that no air space remains in the container. Excess water collected during sampling will be handled according to the procedures outlined in Section 3.1.3.

3.3.4 Onsite Groundwater Parameter Measurement

As indicated on Table 3.1, many of the groundwater chemical parameters will be measured onsite by USEPA NRMRL or Parsons ES personnel. Some of the measurements will be made with direct-reading meters, while others will be made using of a Hach® portable colorimeter in accordance with specific Hach® analytical procedures. These procedures will be described in the following subsections.

All glassware or plasticware used in the analyses will have been cleaned prior to sample collection by thoroughly washing with a solution of Alconox® and water, and rinsing with deionized water and ethanol to prevent interference or cross contamination between measurements. If concentrations of an analyte are above the range detectable by the titrimetric method, the analysis will be repeated by diluting the groundwater sample with double-distilled water until the analyte concentration falls to a level within the range of the method. All rinseate and sample reagents accumulated during groundwater analysis will be collected in glass containers fitted with screw caps. These waste containers will be clearly labeled as to their contents and carefully stored for later transfer to the approved disposal facility.

3.3.4.1 Dissolved Oxygen Measurements

DO measurements will be made using a meter with a downhole oxygen sensor or a sensor in a flow-through cell. Measurements will be taken before and following

groundwater sample acquisition. When DO measurements are taken in monitoring wells/points that have not yet been sampled, the existing monitoring wells/points will be purged until DO levels stabilize. DO measurements will be recorded on the groundwater sampling record (Figure 3.7)

3.3.4.2 pH, Temperature, and Specific Conductance

Because the pH, temperature, and specific conductance of a groundwater sample can change significantly within a short time following sample acquisition, these parameters will be measured in the field in unfiltered, unpreserved, "fresh" water collected by the same technique as the samples taken for laboratory analyses. The measurements will be made in a clean glass container separate from those intended for laboratory analysis, and the measured values will be recorded in the groundwater sampling record (Figure 3.7).

3.3.4.3 Carbon Dioxide Measurements

Carbon dioxide (CO₂) is a byproduct of biological reactions and can be used to evaluate the bioactivity of the groundwater system. CO₂ concentrations in groundwater will be measured in the field by experienced USEPA NRMRL or Parsons ES scientists via titrimetric analysis using CHEMetrics® Method 4500 (0 to 250 mg/L as CO₂), or equivalent.

3.3.4.4 Alkalinity Measurements

Alkalinity in groundwater helps buffer the groundwater system against acids generated through both aerobic and anaerobic biodegradation processes. Alkalinity of the groundwater sample will be measured in the laboratory (Table 3.1), or may be measured in the field by experienced USEPA NRMRL or Parsons ES scientists via titrimetric analysis using USEPA-approved Hach® Method 8221 (0 to 5,000 mg/L as calcium carbonate), or equivalent.

3.3.4.5 Nitrate- and Nitrite-Nitrogen Measurements

Nitrate-nitrogen concentrations are of interest because nitrate can act as an electron acceptor during hydrocarbon biodegradation under anaerobic soil or groundwater conditions. Nitrate-nitrogen is also a potential nitrogen source for hydrocarbon-degrading bacteria biomass formation. Nitrite-nitrogen is an intermediate byproduct in both ammonia nitrification and in nitrate reduction in anaerobic environments.

Nitrate- and nitrite-nitrogen concentrations in groundwater will be measured in the laboratory (Table 3.1), or may be measured in the field by experienced NRMRL or Parsons ES scientists via colorimetric analysis using a Hach® DR/700 Portable Colorimeter. Nitrate concentrations in groundwater samples will be analyzed after preparation with Hach® Method 8039 (0 to 30.0 mg/L nitrate), or equivalent. Nitrite concentrations in groundwater samples will be analyzed after preparation with USEPA-approved Hach® Method 8507 (0 to 0.35 mg/L nitrite), or equivalent.

3.3.4.6 Sulfate and Sulfide Sulfur Measurements

Sulfate in groundwater is a potential electron acceptor for fuel-hydrocarbon biodegradation in anaerobic environments, and sulfide is resultant after sulfate reduction. Sulfate will be measured in the laboratory (Table 3.1), or USEPA NRMRL or Parsons ES scientists may measure sulfate and sulfide concentrations via colorimetric analysis with a Hach® DR/700 Portable Colorimeter after appropriate sample preparation. USEPA-approved Hach® Methods 8051 (0 to 70.0 mg/L sulfate) and 8131 (0.60 mg/L sulfide), or equivalents, will be used to prepare samples and analyze sulfate and sulfide concentrations, respectively.

3.3.4.7 Total Iron, Ferrous Iron, and Ferric Iron Measurements

Iron is an important trace nutrient for bacterial growth, and different states of iron can affect the oxidation/reduction potential of the groundwater and act as an electron acceptor for biological metabolism under anaerobic conditions. Iron concentrations

will be measured in the field via colorimetric analysis with a Hach® DR/700 Portable Colorimeter after appropriate sample preparation. Hach® Method 8008, or equivalent, for total soluble iron (0 to 3.0 mg/L ferric + ferrous iron) and Hach® Method 8146, or equivalent, for ferrous iron (0 to 3.0 mg/L) will be used to prepare and quantitate the samples. Ferric iron will be quantitated by subtracting ferrous iron levels from total iron levels.

3.3.4.8 Manganese Measurements

Manganese is a potential electron acceptor under anaerobic environments. Manganese concentrations will be quantitated in the field using colorimetric analysis with a Hach® DR/700 Portable Colorimeter. USEPA-approved Hach® Method 8034 (0 to 20.0 mg/L), or equivalent, will be used to prepare the samples for quantitation of manganese concentrations.

3.3.4.9 Oxidation/Reduction Potential

The ORP of groundwater is an indicator of the relative tendency of a solution to accept or transfer electrons. Redox reactions in groundwater are usually biologically mediated; therefore, the redox potential of a groundwater system depends upon and influences rates of biodegradation. ORPs can be used to provide real-time data on the location of the contaminant plume, especially in areas undergoing anaerobic biodegradation. The ORP of a groundwater sample taken inside the contaminant plume should be somewhat lower than that of a sample taken in an upgradient location.

The ORP of a groundwater sample can change significantly within a short time following sample acquisition and exposure to atmospheric oxygen. Therefore, this parameter will be measured in the field in unfiltered, unpreserved, "fresh" water collected by the same technique as the samples taken for laboratory analyses. The measurements will be made as quickly as possible in a clean glass container separate from those intended for laboratory analysis.

3.4 MOBILE LNAPL SAMPLING

If a sufficient thickness of mobile LNAPL is detected in a monitoring well at Area A, a sample of mobile LNAPL will be obtained using a disposable Teflon[®] bailer attached to nylon rope. The bailer will be gently lowered into the well in an attempt to minimize agitation. After the mobile LNAPL sample has been collected into the bailer and the bailer has been retrieved, any water accumulated in the bailer will be drained, and the LNAPL sample will be slowly poured into appropriate bottles. Sample packaging, labeling, and handling is described in the following section.

3.5 HANDLING OF SAMPLES FOR LABORATORY ANALYSIS

This section describes the handling of samples from the time of sampling until the samples are delivered to USEPA field laboratory.

3.5.1 Sample Preservation

The USEPA laboratory support personnel will add any necessary chemical preservatives prior to sealing the sample containers. Samples will be prepared for transportation to the analytical laboratory by placing the samples in a cooler containing ice to maintain a shipping temperature of as close to 4 degrees centigrade (°C) as possible. Samples will be delivered promptly to USEPA field laboratory personnel, who will be responsible for shipment of appropriate samples to the NRMRL in Ada, Oklahoma for analysis.

3.5.2 Sample Container and Labels

Sample containers and appropriate container lids will be provided by the USEPA field laboratory (see Appendix A). The sample containers will be filled as described in Sections 3.1.2 and 3.3.3.4, and the container lids will be tightly closed. The sample

label will be firmly attached to the container side, and the following information will be legibly and indelibly written on the label:

- Facility name;
- Sample identification;
- Sample type (e.g., groundwater, soil);
- Sampling date;
- Sampling time;
- Preservatives added;
- Sample collector's initials; and
- Analyses requested.

3.5.3 Sample Shipment

After the samples are sealed and labeled, they will be packaged for transport to the onsite USEPA field laboratory. The packaged samples will be delivered by hand to the USEPA field laboratory. Delivery will occur as soon as possible after sample acquisition.

The following packaging and labeling procedures will be followed:

- Package sample so that it will not leak, spill, or vaporize from its container;
- Cushion samples to avoid breakage; and
- Add ice to container to keep samples cool.

USEPA personnel will be responsible for repackaging and overnight shipment of samples to the NRMRL in Ada, Oklahoma.

3.5.4 Chain-of-Custody Control

Chain-of-custody documentation for the shipment of samples from the USEPA field laboratory to the NRMRL analytical laboratory in Ada, Oklahoma, will be the responsibility of the USEPA field personnel.

3.5.5 Sampling Records

In order to provide complete documentation of the sampling event, detailed records will be maintained by the field scientist. At a minimum, these records will include the following information:

- Sample location (facility name);
- Sample identification;
- Sample location map or detailed sketch;
- Date and time of sampling;
- Sampling method;
- Field observations of
 - Sample appearance, and
 - Sample odor;
- Weather conditions;
- Water level prior to purging (groundwater samples, only);

- Total monitoring well/point depth (groundwater samples, only);
- Sample depth (soil samples, only);
- Purge volume (groundwater samples, only);
- Water level after purging (groundwater samples, only);
- Monitoring well/point condition (groundwater samples, only);
- Sampler's identification;
- Field measurements of pH, temperature, DO, and specific conductivity (groundwater samples, only); and
- Any other relevant information.

Groundwater sampling information will be recorded on a groundwater sampling form. Figure 3.7 shows an example of the groundwater sampling record. Soil sampling information will be recorded in the field log book.

3.5.6 Laboratory Analyses

Laboratory analyses will be performed on all groundwater and soil samples as well as the QA/QC samples described in Section 4. The analytical methods for this sampling event are listed in Table 3.1. Prior to sampling, USEPA NRMRL personnel will provide a sufficient number of analyte-appropriate sample containers for the samples to be collected. All containers, preservatives, and shipping requirements will be consistent with USEPA protocol or those listed in Appendix B of this plan.

USEPA laboratory support personnel will specify the necessary QC samples and prepare appropriate QC sample containers. For samples requiring chemical

preservation, preservatives will be added to containers by the laboratory or USEPA NRMRL field personnel. Containers, ice chests with adequate padding, and cooling media will be provided by USEPA NRMRL laboratory personnel. Sampling personnel will fill the sample containers and return the samples to the field laboratory.

3.6 AQUIFER TESTING

Slug tests will be conducted on newly installed monitoring wells at each site to estimate the hydraulic conductivity of unconsolidated deposits at the sites. This information is required to accurately estimate the velocity of groundwater and contaminants in the shallow saturated zone. A slug test is a single-well hydraulic test used to determine the hydraulic conductivity of an aquifer in the immediate vicinity of the tested well. Slug tests can be used for both confined and unconfined aquifers that have a transmissivity of less than 7,000 square feet per day (ft^2/day). Slug testing can be performed using either a rising head or a falling head test; at this site, both methods will be used in sequence.

3.6.1 Definitions

- **Hydraulic Conductivity (K).** A quantitative measure of the ability of porous material to transmit water; defined as the volume of water that will flow through a unit cross-sectional area of porous or fractured material per unit time under a unit hydraulic gradient.
- **Transmissivity (T).** A quantitative measure of the ability of an aquifer to transmit water. It is the product of the hydraulic conductivity and the saturated thickness.
- **Slug Test.** Two types of testing are possible: rising head and falling head tests. A slug test consists of adding a slug of water or a solid cylinder of known volume to the well to be tested or removing a known volume of water or cylinder and

measuring the rate of recovery of water level inside the well. The slug of a known volume acts to raise or lower the water level in the well.

- **Rising Head Test.** A test used in an individual well within the saturated zone to estimate the hydraulic conductivity of the surrounding formation by lowering the water level in the well and measuring the rate of recovery of the water level. The water level may be lowered by pumping, bailing, or removing a submerged slug from the well.
- **Falling Head Test.** A test used in an individual well to estimate the hydraulic conductivity of the surrounding formation by raising the water level in the well by insertion of a slug or quantity of water, and then measuring the rate of drop in the water level.

3.6.2 Equipment

The following equipment will be used to conduct a slug test:

- Teflon®, PVC, or metal slugs;
- Nylon or polypropylene rope;
- Electric water level indicator;
- Pressure transducer/sensor;
- Field logbook/forms; and
- Automatic data recording instrument (such as the Hermit Environmental Data Logger®, In-Situ, Inc. Model SE1000B, or equivalent).

3.6.3 General Test Methods

Aquifer hydraulic conductivity tests (slug tests) are accomplished by either removal of a slug or quantity of water (rising head) or introduction of a slug (falling head), and then allowing the water level to stabilize while taking water level measurements at closely spaced time intervals.

Because hydraulic testing will be completed on existing wells, it will be assumed that the wells were properly developed and that water levels have stabilized. Slug testing will proceed only after multiple water level measurements over time show that static water levels are in equilibrium. During the slug test, the water level change should be influenced only by the introduction (or removal) of the slug volume. Other factors, such as inadequate well development or extended pumping may lead to inaccurate results; in addition, slug tests will not be performed on wells with free product. The field scientist will determine when static equilibrium has been reached in the well. The pressure transducer, slugs, and any other downhole equipment will be decontaminated prior to and immediately after the performance of each slug test using the procedures described in Section 3.1.3.

3.6.4 Falling Head Test

The falling head test is the first step in the two-step slug testing procedure. The following steps describe procedures to be followed during performance of the falling head test.

1. Decontaminate all downhole equipment prior to initiating the test.
2. Open the well. Where wells are equipped with watertight caps, the well should be unsealed at least 24 hours prior to testing to allow the water level to stabilize. The protective casing will remain locked during this time to prevent vandalism.

3. Prepare the aquifer slug test data form (Figure 3.8) with entries for:

- Borehole/well number,
- Project number,
- Project name,
- Aquifer testing team,
- Climatic data,
- Ground surface elevation,
- Top of well casing elevation,
- Identification of measuring equipment being used,
- Static water level, and
- Date.

4. Measure the static water level in the well to the nearest 0.01 foot.

5. Lower the decontaminated pressure transducer into the well and allow the displaced water to return to its static level. This can be determined by periodic water level measurements until the static water level in the well is within 0.01 foot of the original static water level.

6. Lower the decontaminated slug into the well to just above the water level in the well.

Aquifer Slug Test Data Sheet

Location Tinker AFB FTA 2 / Area A

Job No. 729691.34020

Water Level

Measuring Datum

Weather

Comments

Client AFCEE/RNA

Field Scientist

Total Well Depth_

Elevation of Datum.

Temperature_

Well No. _____

Date_

[illegible]

FIGURE 3.8

AQUIFER SLUG TEST DATA SHEET

Sites FTA 2 and Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

7. Turn on the data logger and quickly lower the slug below the water table, being careful not to disturb the pressure transducer. Follow the owner's manual for proper operation of the data logger.
8. Terminate data recording when the water level stabilizes in the well. The well will be considered stabilized for termination purposes when it has recovered 80 to 90 percent from the initial displacement.

3.6.5 Rising Head Test

After completion of the falling head test, the rising head test will be performed. The following steps describe the rising head slug test procedure.

1. Measure the water level in the well to the nearest 0.01 foot to ensure that it has returned to the static water level.
2. Initiate data recording and quickly withdraw the slug from the well. Follow the owner's manual for proper operation of the data logger.
3. Terminate data recording when the water level stabilizes in the well, and remove the pressure transducer from the well and decontaminate. The well will be considered stabilized for termination purposes when it has recovered 80 to 90 percent from the initial displacement.

3.6.6 Slug Test Data Analysis

Data obtained during slug testing will be analyzed using AQTESOLV™ and the method of Hvorslev (1951) for confined aquifers or the method of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions.

SECTION 4

QUALITY ASSURANCE/QUALITY CONTROL

Field QA/QC procedures will include collection of field duplicates/replicates and rinseate, field, and trip blanks; decontamination of all equipment that contacts the sample medium before and after each use; use of analyte-appropriate containers; and chain-of-custody procedures for sample handling and tracking. All samples to be transferred to the USEPA laboratory for analysis will be clearly labeled to indicate sample number, location, matrix (e.g., groundwater), and analyses requested. Samples will be preserved in accordance with the analytical methods to be used, and water sample containers will be packaged in coolers with ice to maintain a temperature of as close to 4°C as possible.

All field sampling activities will be recorded in a bound, sequentially paginated field notebook in permanent ink. All sample collection entries will include the date, time, sample locations and numbers, notations of field observations, and the sampler's name and signature. Field QC samples will be collected in accordance with the program described below, and as summarized in Table 4.1.

QA/QC sampling will include collection and analysis of duplicate groundwater and replicate soil samples, rinseate blanks, field/trip blanks, and matrix spike samples. Internal laboratory QC analyses will involve the analysis of laboratory control samples (LCSs) and laboratory method blanks (LMBs). QA/QC objectives for each of these samples, blanks, and spikes are described below.

TABLE 4.1
QA/QC SAMPLING PROGRAM
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

QA/QC Sample Type	Frequency to be Collected and Analyzed ^{a/}	Analytes
Duplicates/Replicates	10% of Groundwater and Soil Samples	VOCs, TPH, PAHs, Methane, Geochemical
Rinseate Blanks	5% of Groundwater Samples	VOCs
Field Blanks	5% of Groundwater Samples	VOCs
Trip Blanks	One per shipping cooler containing VOC samples	VOCs
Matrix Spike Samples	One per sampling event	VOCs
Laboratory Control Sample	One per method per medium	Laboratory Control Charts (Method Specific)
Laboratory Method Blanks	One per method per medium	Laboratory Control Charts (Method Specific)

^{a/} Actual frequency of QA/QC samples may be altered by the USEPA field scientists.

Duplicate groundwater and replicate soil samples will be collected at a frequency of 1 for every 10 or fewer samples of similar matrix. Each duplicate groundwater sample will be collected concurrent with, and by the same method, as the primary sample. Replicated soil samples will be collected by mixing a single soil sample interval to obtain a homogeneous sample, and then dividing the soil sample into the primary and replicate soil sample containers. For samples to be analyzed for VOCs, mixing of the soil will be minimized to prevent the loss of volatiles. Duplicate samples will be analyzed for VOCs and geochemical analyses.

One rinseate sample will be collected for every 20 or fewer groundwater samples collected. Because both peristaltic pumps and disposable bailers may be used for this sampling event, the rinseate samples will alternately consist of a sample representing both methods. The peristaltic pump sample will consist of a sample of distilled water pumped through a section of clean tubing and subsequently transferred into a sample container provided by the laboratory. The disposable bailer sample will consist of a sample of distilled water poured into a new disposable bailer and subsequently transferred into a sample container provided by the laboratory. Rinseate samples will be analyzed for VOCs only.

One field blank will be collected for every 20 or fewer groundwater samples to assess the effects of ambient conditions in the field. The field blank will consist of a sample of distilled water poured into a laboratory-supplied sample container while sampling activities are underway. The field blank will be analyzed for VOCs.

A trip blank will be analyzed to assess the effects of ambient conditions on sampling results during the transportation of samples. The trip blank will be prepared by the laboratory. A trip blank will be transported inside each cooler which contains samples for VOC analysis. Trip blanks will be analyzed for VOCs.

Matrix spikes will be prepared in the laboratory and used to establish matrix effects for samples analyzed for VOCs. LCSs and LMBs will be prepared internally by the laboratory and will be analyzed each day samples from the sites are analyzed. Samples will be reanalyzed in cases where the LCS or LMB are out of the control limits. Control charts for LCSs and LMBs will be developed by the laboratory and monitored for the analytical methods used (see Table 3.1).

SECTION 5

DATA ANALYSIS AND REPORT

Once the data collected during the field effort are assembled, they will be analyzed using a variety of methods. For example, isopleth maps of BTEX and CAHs, degradation products, and primary and alternate electron acceptors and donors will be used to evaluate the occurrence and mechanisms of biodegradation at the site, using the relationships discussed in Section 2. In addition, the Thiessen method will be used to estimate contaminant mass in the plume, using data from the latest sampling event and from previous sampling events. The Thiessen method also may be used to evaluate movement of the center of mass of the CAH plume over time, as presented by Dupont *et al.* (1996a and 1996b). This information will give an indication of how contaminant plumes have changed over time, and whether the plumes are stable. If it is apparent that contaminant mass is being lost over time, then it is highly likely that biodegradation is occurring. Site contaminant data also will be used to determine rates of contaminant mass loss and to determine rates of biodegradation. Site data also will be used to estimate contaminant flux through specified areas. Where possible, the data also will be applied to estimate the impacts of other ongoing or planned remedial actions at Sites FTA 2 and Area A.

After the data evaluation and analysis, numerical and/or analytical groundwater models will be used to evaluate the fate and transport of fuel hydrocarbons and chlorinated solvents dissolved in groundwater at both sites. The contaminant fate and transport modeling effort has three primary objectives: 1) predict the future extent and concentration of dissolved contaminant plumes by modeling the effects of advection,

dispersion, sorption, and biodegradation; 2) assess the possible exposure of potential downgradient receptors to contaminant concentrations that exceed levels intended to be protective of human health and the environment; and 3) to provide technical support for selection of RNA as the best remedial alternative at regulatory negotiations, as appropriate.

Based upon model predictions of contaminant concentrations and distribution through time, and upon potential exposure pathways, the potential risk to human health and the environment will be assessed. If it is shown that RNA of BTEX compounds and CAHs at FTA 2 and Area A is sufficient to reduce the potential risk to human health and the environment to acceptable levels, Parsons ES will recommend implementation of the RNA with LTM option. If RNA is chosen, Parsons ES will prepare site-specific, LTM plans that will specify the location of point-of-compliance monitoring wells and sampling frequencies.

If RNA alone is deemed inappropriate for use at these sites, institutional controls such as groundwater or land use restrictions will be evaluated to determine if they will be sufficient to reduce the risk to human health and the environment to acceptable levels. If institutional controls are inappropriate, remedial options that could reduce risks to acceptable levels will be evaluated, and appropriate remedial options will be recommended. Potential remedial options include, but are not limited to: free product recovery (e.g., bioslurping), groundwater pump-and-treat, enhanced biological treatment, air sparging, and *in situ* reactive barrier walls. The reduction in dissolved BTEX and CAHs that should result from remedial activities will be used to produce new input files for the groundwater models. The models will then be used to predict the BTEX and CAH plume, and risk, reduction that should result from remedial actions.

A report detailing the results of the modeling and remedial option evaluation will be prepared. This report will follow the outline presented in Table 5.1 and will contain an introduction, site descriptions, identification of remediation objectives, description of remediation alternatives, an analysis of remediation alternatives, and the suggested remedial approach for each site. This report will also contain the results of the site characterization activities described herein.

TABLE 5.1
EXAMPLE REPORT OUTLINE
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

INTRODUCTION

Scope and Objectives
Site Background

SITE CHARACTERIZATION ACTIVITIES

Sampling and Aquifer Testing Procedures

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

Surface Features
Regional Geology and Hydrogeology
Site Geology and Hydrogeology
Climatological Characteristics

NATURE AND EXTENT OF CONTAMINATION

Source Characterization
Soil and Source Chemistry (if source is located)
 Residual Contamination
 Total Organic Carbon
Groundwater Chemistry
 Dissolved Contamination
 Groundwater Geochemistry
Discussion of Results
 Evidence of Biodegradation/Cometabolism
 Calculation of Biodegradation Rates
 Expressed Assimilative Capacity

GROUNDWATER FLOW AND SOLUTE TRANSPORT MODELING

Model Description
Conceptual Model Design and Assumptions
Initial Model Setup
Model Calibration
Sensitivity Analysis
Model Results
Conclusions

TABLE 5.1 (Continued)
EXAMPLE REPORT OUTLINE
SITES FTA 2 AND AREA A
RNA TS
TINKER AFB, OKLAHOMA

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

Remedial Alternatives Evaluation Criteria

Long-Term Effectiveness

Implementability (Technical, Administrative)

Cost (Capital, Operating, Present Worth)

Factors Influencing Alternatives Development

Program Objectives

Contaminant Properties

Site-Specific Conditions

Brief Description of Remedial Alternatives

Intrinsic Remediation with Long-Term Monitoring

Other Alternatives

Evaluation of Alternatives

Recommended Remedial Approach

LONG-TERM MONITORING PLAN

Overview

Monitoring Networks

Groundwater and Surface Water Sampling

CONCLUSIONS AND RECOMMENDATIONS

APPENDICES: Supporting Data and Documentation

Site-Specific Model Input and Results

SECTION 6

REFERENCES

- Altenschmidt, U. and Fuchs, G., 1991, Anaerobic degradation of toluene in denitrifying *Pseudomonas* sp.: Indication for toluene methylhydroxylation and benzoyl-CoA as central aromatic intermediate: Arch. Microbial., vol. 156, p. 152-158.
- Alvarez, P.J.J., and Vogel, T.M., 1991, Substrate interactions of benzene, toluene, and para-xylene during microbial degradation by pure cultures and mixed culture aquifer slurries: Applied Environmental Microbiology, vol. 57, p. 2981-2985.
- Alvarez-Cohen, L.M. and McCarty, P.L., 1991a, Effects of toxicity, aeration, and reductant supply on trichloroethylene transformation by a mixed methanotrophic culture: Appl. Environ. Microbiol., vol. 57, no. 1, p. 228-235.
- Alvarez-Cohen, L.M., and McCarty, P.L., 1991b, Product toxicity and cometabolic competitive inhibition modeling of chloroform and trichloroethylene transformation by methanotrophic resting cells: Appl. Environ. Microbiol., vol. 57, no. 4, p. 1031-1037.
- Arciero, D., Vannelli, T., Logan, M., and Hooper, A.B., 1989, Degradation of trichloroethylene by the ammonia-oxidizing bacterium *Nitrosomonas europaea*: Biochem. Biophys. Res. Commun., vol. 159, p. 640-643.

- Atlas, R.M., 1981, Microbial degradation of petroleum hydrocarbons - an environmental perspective: Microbiological Reviews, vol. 45, no. 1, p. 180-209.
- Atlas, R.M., 1984, Petroleum Microbiology: Macmillan Publishing Company, New York.
- Atlas, R.M., 1988, Microbiology - Fundamentals and Applications: Macmillan Publishing Company, New York.
- Baedecker, M.J., Siegel, D.I., Bennett, P.C., Cozzarelli, I.M., 1988, The fate and effects of crude oil in a shallow aquifer: I. The distribution of chemical species and geochemical facies, In: G.E. Mallard, and S.E. Ragone, editors, U.S. Geological Survey Toxic Substances Hydrology Program, Proceedings of the Technical Meeting, Phoenix, Arizona, September 26-30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88-42320, p. 29-22.
- Baedecker, M.J., and Cozzarelli, I.M., 1991, Geochemical modeling of organic degradation reactions in an Aquifer contaminated with Crude Oil: U.S. Geological Survey Water-Resources Investigations Report 91-4034. Reston, VA. p 627-632.
- Ball, H.A., Reinhard, M., and McCarty, P.L., 1991, Biotransformation of monoaromatic hydrocarbons under anoxic conditions, In: In Situ Bioreclamation, Applications and Investigations for Hydrocarbon and Contaminated Site Remediation. Eds. R.E. Hincbee and R.F. Olfenbuttel. Butterworth-Heinemann. Boston, MA. p. 458-463.

- Barker, J.F., Patrick, G.C., and Major, D., 1987, Natural attenuation of aromatic hydrocarbons in a shallow sand aquifer: *Ground Water Monitoring Review*, Winter, 1987, p. 64-71.
- Bartha, R., 1986, Biotechnology of petroleum pollutant biodegradation: *Microbial Ecology*, vol. 12, p. 155-172.
- Bauman, B., 1991, Biodegradation research of the American Petroleum Institute. Presented at: *In Situ Bioreclamation: Application and Investigation for Hydrocarbons and Contaminated Site Remediation*. San Diego, CA. March 19-21, 1991.
- Beller, H.R. Reinhard, M., and Grbic-Galic, D., 1992, Metabolic byproducts of anaerobic toluene degradation by sulfate-reducing enrichment cultures: *Appl. Environ. Microbiol.*, vol. 58, p. 3192-3195.
- Bingham, R.H. and R.L. Moore, 1975, Reconnaissance of the Water Resources of the Oklahoma City Quadrangle, Central Oklahoma, Oklahoma Geological Survey, Hydrologic Atlas 4.
- Borden, R.C., 1991, Simulation of enhanced in situ bioremediation of petroleum hydrocarbons. In: *In Situ bioreclamation: Application and Investigation for Hydrocarbons and contaminated Site Remediation*. Eds., R.E. Hinchee and R. F. Olfenbittel. Butterworth-Heinemann. p. 529-534.
- Bouwer, E.J., Rittman, B.E., and McCarty, P.L., 1981, Anaerobic degradation of halogenated 1- and 2-carbon organic compounds: *Environ. Sci. Technol.*, vol. 15, no. 5, p. 596-599.
- Bouwer, E.J. and Wright, J.P., 1988, Transformations of trace halogenated aliphatics in anoxic biofilm columns: *J. Contam. Hydrol.*, vol. 2, p. 155-169.

- Bouwer, E.J., 1992, Bioremediation of Subsurface Contaminants, In: Mitchell, R., ed.: Environmental Microbiology. Wiley-Liss, New York, New York.
- Bouwer, E.J., 1994, Bioremediation of chlorinated solvents using alternate electron acceptors. In: Handbook of Bioremediation. CRC Press, Boca Raton, FL.
- Bouwer, H., 1989, The Bouwer and Rice slug test - an update: Ground Water, 27(3), p. 304-309.
- Bouwer, H., and Rice, R.C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells: Water Resources Research, 12(3), p. 423-428.
- Bradley, P.M., and Chapelle, F.H., 1996, Anaerobic mineralization of vinyl chloride in Fe(III)-reducing aquifer sediments: Accepted for publication in Environmental Science and Technology, 1996.
- Brown, R.A., Dey, J.C. and McFarland, W.E., 1991, Integrated site remediation combining groundwater treatment, soil vapor extraction, and bioremediation, In: In Situ Bioreclamation: Application and Investigation for Hydrocarbons and Contaminated Site Remediation. Eds., R.E. Hinchey and R. F. Olfenbittel. Butterworth-Heinemann. p. 444-449.
- Bruce, L., Miller, T., and Hockman, B., 1991, Solubility versus equilibrium saturation of gasoline compounds - a method to estimate fuel/water partition coefficient using solubility or K_{oc} . In, NWWAI/API Conference on Petroleum Hydrocarbons in Ground Water: NWT/API, A. Stanley (ed.), p. 571-582.
- Chiang, C.Y., Salanitro, H.P., Chai, E.Y., Colthart, H.D., and Klein, C.L., 1989, Aerobic biodegradation of benzene, toluene, and xylene in a sandy aquifer - data analysis and computer modeling: Ground Water, vol. 27, no. 6, p. 823-834.

- Cline, P.V., and Delfino, J.J., 1989, Transformation kinetics of 1,1,1-trichloroethane to the stable product 1,1-dichloroethene, In: Biohazards of Drinking Water Treatment. Lewis Publishers, Inc. Chelsea, MI. p. 47-56.
- Cline, P.V., Delfino, J.J., and Rao, P.S.C., 1991, Partitioning of aromatic constituents into water from gasoline and other complex solvent mixtures: Environmental Science and Technology, v.17, No. 4, p. 227-231.
- Cozzarelli, I.M., R.P. Eganhouse, and M.J. Baedecker. 1990. Transformation of Monoaromatic Hydrocarbons to Organic Acids in Anoxic Ground Water Environment: Environmental and Geological Water Science, vol. 16.
- Davis, J.W., Klier, N.J., and Carpenter, 1994, Natural biological attenuation of benzene in ground water beneath a manufacturing facility: Ground Water, vol. 32, no. 2, p. 215-226.
- DeStefano, T.D., Gossett, J.M., and Zinder, S.H., 1991, Reductive dehalogenation of high concentrations of tetrachloroethene to ethene by an anaerobic enrichment culture in the absence of methanogenesis: Appl. Environ. Microbiol., vol. 57, no. 8, p. 2287-2292.
- Dupont, R.R., Gorder, K., Sorenson, D.L., and Kemblowski, M., 1996a, Assessment and quantification of intrinsic remediation at a chlorinated solvent/hydrocarbon contaminated site, Eielson AFB, Alaska: In: Conference on Intrinsic Remediation of Chlorinated Solvents. Salt Lake City, UT. April 2, 1996.
- Dupont, R.R., Gorder, K., Sorenson, D.L., and Kemblowski, M., 1996b, Field evaluation of intrinsic remediation at a chlorinated solvent/hydrocarbon contaminated site, Eielson AFB, Alaska: In: Conference on Intrinsic Remediation of Chlorinated Solvents. Salt Lake City, UT. April 2, 1996.

- Edwards, E., Wills, L.E., Grbic-Galic, D., and Reinhard, M., 1991, Anaerobic degradation of toluene and xylene--evidence for sulfate as the terminal electron acceptor, In: In Situ Bioreclamation, Applications and Investigations for Hydrocarbon and Contaminated Site Remediation. Eds. R.E. Hinchee and R.F. Olfenbittel. Butterworth-Heinemann. Boston, MA. p. 463-471.
- Edwards, E.A., and Grbic-Galic, D., 1992, Complete mineralization of benzene by aquifer microorganisms under strictly anaerobic conditions: Appl. Environ. Microbiol., vol. 58, p. 2663-2666.
- Edwards, E.A., Wells, L.E., Reinhard, M., and Grbic-Galic, D., 1992, Anaerobic degradation of toluene and xylene by aquifer microorganisms under sulfate-reducing conditions: Appl. Environ. Microbiol., vol. 58, p. 794-800.
- Engineering-Science, Inc. (ES), 1982, Installation Restoration Program, Phase I - Records Search, Tinker AFB, Oklahoma.
- Evans, P.J., Mang, D.T., and Young, L.Y., 1991a, Degradation of toluene and m-xylene and transformation of o-xylene by denitrifying enrichment cultures: Appl. Environ. Microbiol., vol. 57, p.450-454.
- Evans, P.J., Mang, D.T., Kim, K.S., and Young, L.Y., 1991b, Anaerobic degradation of toluene by a denitrifying bacterium: Appl. Environ. Microbiol., vol. 57, p. 1139-1145.
- Environmental Recovery, Inc., 1990, Underground Storage Tank Site Assessment Report, Submitted by USACE Tulsa District, July 1990.
- Folsom, B.R., Chapman, P.J., and Pritchard, P.H., 1990, Phenol and trichloroethylene degradation by *Pseudomonas cepacia* G4: Kinetics and

interactions between substrates: Appl. Environ. Microbiol., vol. 56, no. 5, p. 1279-1285.

Freedman, D.L., and Gossett, J.M., 1989, Biological reductive dehalogenation of tetrachloroethylene and trichloroethylene to ethylene under methanogenic conditions: Appl. Environ. Microbiol., vol. 55, no. 4, p. 1009-1014.

Gibson, D.T., and Subramanian, V., 1984, Microbial degradation of aromatic hydrocarbons, In: Gibson, D.T., ed: Microbial Degradation of Organic Compounds, Marcel Dekker, Inc., p. 181-252.

Godsey, E.M. 1994. Microbiological and Geochemical Degradation Processes, In: Symposium on Intrinsic Bioremediation in Ground Water. Denver, Colorado. August 30 - September 1. p.35-40.

Grbic-Galic, D., 1989, Microbial degradation of homocyclic and heterocyclic aromatic hydrocarbons under conditions: Dev. Ind. Microbiol., vol. 30, p. 237-253.

Grbic-Galic, D., 1990, Anaerobic microbial transformation of nonoxygenated aromatic and alicyclic compounds in soil, subsurface, and freshwater sediments, In: Bollag, J.M., and Stotzky, G., eds.: Soil Biochemistry: Marcel Dekker, Inc., New York, NY. p. 117-189.

Haag, F., Reinhard, M., and McCarty, P.L., 1991, Degradation of toluene and p-xylene in an anaerobic microcosms: Evidence for sulfate as a terminal electron acceptor: Environ. Toxicol. Chem., vol. 10, p. 1379-1389.

Harker, A.R., and Kim, Y., 1990, Trichloroethylene degradation by two independent aromatic-degrading pathways in *Alcaligenes eutrophus* JMP134: Appl. Environ. Microbiol., vol. 56, no. 4, p. 1179-1181.

- Hartmans, S., and de Bont, J.A.M., 1992, Aerobic vinyl chloride metabolism in *Mycobacterium aurum* Li: Appl. Environ. Microbiol., vol. 58, no. 4, p. 1220-1226.
- Henry, S.M., 1991, Transformation of Trichloroethylene by Methanotrophs from a Groundwater Aquifer. Ph.D. Thesis. Stanford University. Palo Alto, California.
- Hutchins, S.R., and Wilson, J.T., 1991, Laboratory and field studies on BTEX biodegradation in a fuel-contaminated aquifer under denitrifying conditions, In: In Situ Bioreclamation, Applications and Investigations for Hydrocarbon and Contaminated Site Remediation. Eds. R.E. Hincbee and R.F. Olfenbuttel. Butterworth-Heinemann. Boston, MA. p. 157-172.
- Hutchins, S.R., Sewell, G.W., Sewell, D.A., Kovacs, D.A., and Smith, G.A., 1991a, Biodegradation of monoaromatic hydrocarbons by aquifer microorganisms using oxygen, nitrate, or nitrous oxide as the terminal electron acceptor: Environ. Sci. Technol., vol. 25, no. 1, p. 68-76.
- Hutchins, S.R., Downs, W.C., Smith, G.B., Smith, J.T., Wilson, D.J., Hendrix, D.J., Fine, D.D., Kovacs, D.A., Douglass, R.H., and Blaha, F.A., 1991b, Nitrate for Biorestitution of an Aquifer Contaminated with Jet Fuel. U.S. Environmental Protection Agency. Robert S. Kerr Environmental Research Laboratory. Ada, Oklahoma. epa/600/2-91/009. April, 1991.
- Hvorslev, M. J., 1951, *Time Lag and Soil Permeability in Ground-Water Observations*: United States Corps of Engineers Waterways Experiment Station Bulletin 36, Vicksburg, Mississippi. 50p.

- IT Corporation, 1993, Description of Current Conditions, Investigation of Miscellaneous Fuel Yards, Contract No. F34650-93-D-0107, Delivery Order 5000, IT Project No. 409802.01, July 1993.
- IT Corporation, 1994, Final Report Phase I RCRA Facility Investigation for Appendix I Sites, Tinker AFB, Oklahoma, September 1994.
- IT Corporation, 1995a, Final RCRA Facility Investigation Report - Area A Service Station, Contract No. F34650-93-D-0107, Delivery Order 5000, IT Project No. 409802, March 1995.
- IT Corporation, 1995b, Final Work Plan Basewide Non-NPL Groundwater Phase II RCRA Facility Investigation for Appendix I and II SWMUs, Contract No. F34650-93-D-0107, Delivery Order 5003, IT Project No. 409981, April, 1995.
- IT Corporation, 1995c, Final Temporary Groundwater Probe Investigation Report, Contract No. F34650-93-D-0107, Delivery Order 5006, IT Project No. 762321, September, 1995.
- IT Corporation, 1996, Investigation for Soil and Groundwater Cleanup Report, Area A Service Station, Tinker AFB, Oklahoma. January 1996.
- Jamison, V.W., Raymond, R.L., and Hudson, J.O. Jr., 1975, Biodegradation of high-octane gasoline in ground water: Developments in Industrial Microbiology, vol. 16.
- Klier, N.J., West, R.J., and Donberg, P.A., 1996, Aerobic Biodegradation of Dichloroethylenes in Surface and Subsurface Soils: Accepted for Publication in Chemosphere, December 1996.

- Leahy, J.G., and Colewell, R.R., 1990, Microbial degradation of hydrocarbons in the environment: *Microbiological Reviews*, vol. 53, no. 3, p. 305-315.
- Lee, M.D, 1988, "Biore Restoration of Aquifers Contaminated with Organic Compounds." *CRC Critical Reviews in Environmental Control*, v. 18. p. 29-89.
- Little, C.D., Palumbo, A.V., Herbes, S.E., Lidstrom, M.E., Tyndall, R.L., and Gilmer, P.J., 1988, Trichloroethylene biodegradation by a methane-oxidizing bacterium: *Appl. Environ. Microbiol.*, vol. 54, no. 4, p. 951-956.
- Malone, D.R., Kao, C.M., and Borden, R.C., 1993, Dissolution and biore Restoration of nonaqueous phase hydrocarbons - models development and laboratory evaluation: *Water Resources Research*, vol. 29, no. 7, p. 2003-2213.
- Mayer, K.P., Grbic-Galic, D., Semprini, L., and McCarty, P.L., 1988, Degradation of trichloroethylene by methanotrophic bacteria in a laboratory column of saturated aquifer material: *Wat. Sci. Tech. (Great Britain)*, vol. 20, no. 11/12, p. 175-178.
- McCarty, P.L., Roberts, P.V., Reinhard, M., and Hopkins, G., 1992, Movement and transformations of halogenated aliphatic compounds in natural systems, In: *Fate of Pesticides and Chemicals in the Environment*. Ed., J.L. Schnoor. John Wiley & Sons, Inc. New York, New York. p. 191-209.
- McCarty, P.L., and Semprini, L., 1994, Ground-Water Treatment for Chlorinated Solvents, In: *Handbook of Bioremediation*. Lewis Publishers, Boca Raton, FL. 1994.

- Miller, R.E., and Guengerich, F.P., 1982, Oxidation of trichloroethylene by liver microsomal cytochrome P-450: Evidence for chlorine migration in a transition state not involving trichloroethylene oxide: *Biochemistry*, vol. 21, p. 1090-1097.
- Miser, Hugh D., et al., 1954, *Geologic Map of the State of Oklahoma*, Oklahoma Geological Survey.
- Murray, W.D. and Richardson, M., 1993, Progress toward the biological treatment of C₁ and C₂ halogenated hydrocarbons: *Critical Reviews in Environmental Science and Technology*, v. 23, no. 3, pp. 195-217.
- Nelson, M.J.K., Montgomery, S.O., O'Neill, E.J., and Pritchard, P.H., 1986, Aerobic metabolism of trichloroethylene by a bacterial isolate: *Appl. Environ. Microbiol.*, vol. 52, no. 2, p. 949-954.
- Parkhurst, D.L., Christenson, S.C., and Breit, G.N., 1993, *Groundwater-Water-Quality Assessment of the Central Oklahoma Aquifer, Oklahoma: Geochemical and Geohydrologic Investigations: U.S. Geological Survey Open-File Report 02-642*, 216p.
- Parsons ES, 1996, *Program Health and Safety Plan for the Demonstration of Remediation by Natural Attenuation*. August.
- Parsons ES, 1997, *Tinker AFB Addendum to the Program Health and Safety Plan* (pending).
- Reinhard, M., Goodman, N.L., and Barker, J.F., 1984, Occurrence and distribution of organic chemicals in two landfill leachate plumes: *Environ. Sci. Technol.*, vol. 18, no. 12, p. 953-961.

State of Oklahoma Water Resources Board, 1994, Water Quality Standards as of June 13, 1994.

Stumm, W. and Morgan, J.J. 1981. Aquatic Chemistry. John Wiley & Sons, New York, NY.

Tetra Tech, Inc., 1996, RCRA Facility Investigation for Selected Appendix I Sites, Tinker AFB, Oklahoma, RFI Draft, October 1996.

Thierrin, J., Davis, G.B., Barber, C., Patterson, B.M., Pribac, F., Power, T.R., and Lambert, M., 1992, Natural degradation rates of BTEX compounds and naphthalene in a sulfate-reducing ground water environment, In: In-Situ Bioremediation Symposium "92". Niagara-on-the-Lake, Ontario, Canada. September 20-24, 1992: In Press.

Tinker AFB, 1991, Natural Resources Management Plan, August 1991.

Tinker AFB, 1996, File Records and Basewide Annual Groundwater Sampling Database, Restoration Division.

U.S. Army Corps of Engineers (USACE), 1988, Tinker Air Force Base, Installation Restoration Program, Fire Training Area No. 2, Tulsa District, December 1988.

van Genuchten, M. T., and Alves, W. J., 1982, Analytical Solutions of the One-Dimensional Convective-Dispersive Solute Transport Equation: US Department of Agriculture, Technical Bulletin Number 1661, 151p.

Vogel, T.M., 1994, Natural Bioremediation of Chlorinated Solvents, In: Handbook of Bioremediation. Lewis Publishers, Boca Raton, FL. 1994.

Vogel, T.M., and McCarty, P.L., 1985, Biotransformation of tetrachloroethylene to trichloroethylene, dichloroethylene, vinyl chloride, and carbon dioxide under methanogenic conditions: *Applied Environmental Microbiology*, v. 49, no. 5, pp. 1080-1083.

Vroblesky, D.A. and F.H. Chapelle. 1994. Temporal and Spatial Changes of Terminal Electron-Accepting Processes in a Petroleum Hydrocarbon-Contaminated Aquifer and the Significance for Contaminant Biodegradation: *Water Resources Research*, v. 30, no. 5, p. 1561-1570.

Water and Soil Consultants, Inc. (WSCl), 1992, Draft Remedial Investigation Report - POL Site Area "A" - Former Motor Fuel Dispensing Station, Tinker Air Force Base, Oklahoma, Contract No. F34650-90-C-0164, September 1992.

Wexler, E.J., 1992, Analytical solutions for one-, two-, and three-dimensional solute transport in ground-water systems with uniform flow: *United States Geological Survey, Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3, Chapter B7, 190p.*

Wiedemeier, T.H., Wilson, J.T., Kampbell, D.H., Miller, R.N., and Hansen, J.E., 1995, *Technical Protocol for Implementing Intrinsic Remediation with Long-term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Ground Water*. Prepared by the Air Force Center for Environmental Excellence.

Wiedemeier, T.H., Hansen, J.E., Haas, P., Wilson, J.T., Kampbell, D.H., and Chapelle, F.H., 1996a, *Technical Protocol for Natural Attenuation of Chlorinated Aliphatic Hydrocarbons in Groundwater*. Prepared by the Air Force Center for Environmental Excellence (Draft).

- Wiedemeier, T.H., Benson, L.A., Wilson, J.T., Kampbell, D.H., Hansen, J.E., and Miknis, R., 1996b, Patterns of natural attenuation of chlorinated aliphatic hydrocarbons at Plattsburgh Air Force Base, New York: In: Conference on Intrinsic Remediation of Chlorinated Solvents. Salt Lake City, UT. April 2, 1996.
- Wilson, B.H., Smith, G.B., and Rees, J.F., 1986, Biotransformations of Selected Alkylbenzenes and Halogenated Aliphatic Hydrocarbons in Methanogenic Aquifer Material: A Microcosm Study: Environmental Science and Technology, 20(10):997-1002.
- Wilson, B.H., Bledsoe, B., and Kampbell, D., 1987, Biological processes occurring at an aviation gasoline spill site, In: R.C. Averett and D.M. McKnight editors, Chemical Quality of Water and the Hydrologic Cycle. Lewis Publishers, Chelsea, Michigan, p.125-137.
- Wilson, B.H., J.T. Wilson, D.H. Kampbell, B.E. Bledsoe, and J.M. Armstrong. 1990. Biotransformation of Monoaromatic and Chlorinated Hydrocarbons at an Aviation Gasoline Spill Site: Geomicrobiology Journal, 8:225-240.
- Wilson, J.T., and Wilson, B.H., 1985, Biotransformation of trichloroethylene in soil: Appl. Environ. Microbiol., vol. 49, no. 1, p. 242-243.
- Wilson, J.T., 1996, Personal communication between John Wilson of the USEPA NRMRL and Todd Wiedemeier of Parsons ES regarding USEPA definition of the term "natural attenuation", citing USEPA guidance undergoing internal review.
- Wood, P.R., and Burton, L.C., 1968, Groundwater-Resources, Cleveland and Oklahoma Counties, Oklahoma Geological Survey, Circular 71.

Young, L.Y., 1984, Anaerobic degradation of aromatic compounds, In: Gibson, D.R., ed.: Microbial Degradation of Aromatic Compounds. Marcel-Dekker, New York.

APPENDIX A

**CONTAINERS, PRESERVATIVES, PACKAGING, AND SHIPPING
REQUIREMENTS FOR GROUNDWATER SAMPLES**

APPENDIX A

ANALYTICAL METHODS, DATA USE, AND SAMPLE PACKAGING

REQUIREMENTS FOR SOIL AND WATER SAMPLES

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Soil	Total volatile and extractable hydrocarbons,	Gas chromatography (GC) method SW8015 [modified]	Handbook method; reference is the California LUFT manual	Data are used to determine the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Aromatic and Chlorinated hydrocarbons (BTX, PCE, TCE, DCE, VC)	Purge and trap GC method SW8240	Handbook method modified for field extraction of soil using methanol	Data are used to determine the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Total organic carbon (TOC)	SW9060 modified for soil samples	Procedure must be accurate over the range of 0.01–15 percent TOC	The rate of migration of petroleum contaminants in groundwater is dependent upon the amount of TOC in the aquifer matrix.	At initial sampling	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Moisture	ASTM D-2216	Handbook method	Data are used to correct soil sample analytical results for moisture content (e.g., report results on a dry weight basis).	Each soil sampling round	Use a portion of soil sample collected for another analysis	Fixed-base

APPENDIX A (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Aromatic and chlorinated hydrocarbons (BTEX, trimethylbenzene isomers, PCE, TCE, DCE, VC, chloromethane, chloroform, other relevant compounds)	Methods SW8010/8020 or SW8240	Handbook methods; analysis may be extended to higher molecular weight alkylbenzenes	Method of analysis for BTEX & CAHs, which are the primary target analytes for monitoring natural attenuation; BTEX & CAH concentrations must also be measured for regulatory compliance; trimethylbenzenes are used to monitor BTEX plume dilution if degradation is primarily anaerobic. Chloromethane and chloroform are indicators of CAH contamination by aerobic pathways.	Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Fixed-base
Water	Polycyclic aromatic hydrocarbons (PAHs) (optional)	GC/mass spectroscopy method SW8270; high-performance liquid chromatography method SW8310	Analysis needed only when required for regulatory compliance.	PAHs are components of fuel and are typically analyzed for regulatory compliance; data on their concentrations are not used currently in the evaluation of natural attenuation.	As required by regulations	Collect 1 L of water in a glass container; cool to 4°C	Fixed-base
Water	Oxygen	Dissolved oxygen meter	Refer to method A4500 for a comparable laboratory procedure.	The oxygen concentration is a data input to the Bioplume model; concentrations less than 1 mg/L generally indicate an anaerobic pathway.	Each sampling round	Measure dissolved oxygen on site using a flow-through cell	Field

APPENDIX A (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Nitrate	IC method E300	Method E300 is a Handbook method.	Substrate for microbial respiration if oxygen is depleted.	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; add H_2SO_4 to pH 2, cool to 4°C	Fixed-base
Water	Iron (II) (Fe^{2+})	Colorimetric Hach Method # 8146	Filter if turbid.	May indicate an anaerobic degradation process due to depletion of oxygen, and nitrate.	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Sulfate (SO_4^{2-})	IC method E300	Method E300 is a Handbook method, if this method is used for sulfate analysis, do not use the field method.	Substrate for anaerobic microbial respiration	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base
Water	Sulfate (SO_4^{2-})	Hach method # 8051	Colorimetric, if this method is used for sulfate analysis, do not use the fixed-base laboratory method.	Same as above	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Field
Water	Methane, ethane, and ethene	Kampbell <i>et al.</i> , 1989 or SW3810 Modified	Method published by researchers at the US Environmental Protection Agency.	The presence of CH_4 suggests BTEX or other carbon degradation via methanogenesis. Ethane and ethene data are used where chlorinated solvents are suspected of undergoing anaerobic biological transformation.	Each sampling round	Collect water samples in 50 mL glass serum bottles with butyl gray/Teflon-lined caps; add H_2SO_4 to pH 2, cool to 4°C	Fixed-base

APPENDIX A (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Carbon dioxide	Hach test kit model CA-23; Chemetrics Method R-1910	Titrimetric; alternate method	The presence of free CO ₂ dissolved in groundwater is unlikely because of the carbonate buffering system of water, but if detected, the CO ₂ concentrations should be compared with background levels to determine if they are elevated; elevated concentrations of CO ₂ could indicate biodegradation of dissolved contaminants.	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Alkalinity	Hach Alkalinity test kit model AL AP MG-L	Phenolphthalein method	General water quality parameter used (1) as a marker to verify that all site samples are obtained from the same groundwater system and (2) to measure the buffering capacity of groundwater.	Each sampling round	Collect 100 mL of water in glass container	Field
Water	Oxidation-reduction potential (ORP)	A2580B	Measurements made with electrodes; results are displayed on a meter; protect samples from exposure to oxygen. Report results against a silver/silver chloride reference electrode	The ORP of groundwater influences and is influenced by the nature of the biologically mediated degradation of contaminants; the ORP of groundwater may range from more than 800 mV to less than -400 mV.	Each sampling round	Collect 100-250 mL of water in a glass container, filling container from bottom; analyze immediately	Field

APPENDIX A (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	pH	Field probe with direct reading meter.	Field	Aerobic and anaerobic processes are pH-sensitive.	Each sampling round	Collect 100–250 mL of water in a glass or plastic container; analyze immediately	Field
Water	Temperature	Field probe with direct reading meter.	Field only	Well development.	Each sampling round	Not Applicable	Field
Water	Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system.	Each sampling round	Collect 100–250 mL of water in a glass or plastic container	Field
Water	Chloride	Mercuric nitrate titration A4500-Cl ⁻ C	Ion chromatography (IC) method E300 or method SW9050 may also be used	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system; elevated concentrations may also indicate biodegradation of CAHs.	Each sampling round	Collect 250 mL of water in a glass container	Fixed-base
Water	Chloride (optional, see data use)	Hach Chloride test kit model 8-P	Silver nitrate titration	As above, and to guide selection of additional data points in real time while in the field.	Each sampling round	Collect 100mL of water in a glass container	Field
Water	Total Organic Carbon		Laboratory	Used to classify plume and to determine if CAH biodegradation is possible in the absence of anthropogenic carbon.	Each sampling round	Collect 100 mL of water in a glass container, cool	Laboratory

APPENDIX A (concluded)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
ADDITIONAL (OPTIONAL) ANALYSES							
Water	Biochemical Oxygen Demand	EPA Method 405.1			Each sampling round	Collect 2 L of water in a glass container, cool to be determined	Laboratory
Water	Hydrogen (H ₂)		Relatively new analysis; data useful for evaluating biodegradation processes operating at a given time	Indicator of terminal electron-accepting processes operating at a site.	Each sampling round		
Water	Oxygenates (including methanol and acetone)	Optional; SW 8015 Modified			Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Laboratory
Water	Alcohols, ethers, and acetic acids	Optional; SW 8015 Modified		Optional carbon sources for biodegradation.	Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Laboratory
Water	Acetaldehydes	Optional; GC/MS method to be determined			Each sampling round	to be determined	Laboratory
Water	Aliphatic Fatty Acids	Optional; GC/MS method to be determined		Byproducts of biodegradation processes; indicators of biodegradation and cometabolism.	Each sampling round	to be determined	Laboratory
Water	Organic Acids	Optional; GC/MS method to be determined		Optional carbon sources and byproducts of biodegradation processes.	Each sampling round	to be determined	Laboratory

NOTES:

- * Analyses other than those listed in this table may be required for regulatory compliance.
- 1. "Hach" refers to the Hach Company catalog, 1990.
- 2. "A" refers to *Standard Methods for the Examination of Water and Wastewater*, 18th edition, 1992.
- 3. "E" refers to *Methods for Chemical Analysis of Water and Wastes*, USEPA, 1983.
- 4. "Protocols" refers to the AFCEE *Environmental Chemistry Function Installation Restoration Program Analytical Protocols*, 11 June 1992.
- 5. "Handbook" refers to the AFCEE *Handbook to Support the Installation Restoration Program (IRP) Remedial Investigations and Feasibility Studies (RI/FS)*, September 1993.
- 6. "SW" refers to the *Test Methods for Evaluating Solid Waste, Physical, and Chemical Methods*, SW-846, USEPA, 3rd edition, 1986.
- 7. "ASTM" refers to the *American Society for Testing and Materials*.
- 8. "LUFT" refers to the State of California *Leaking Underground Fuel Tank Field Manual*, 1988 edition.

APPENDIX B

**ADDITIONAL SITE DATA
SITE FTA 2**

Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-62B

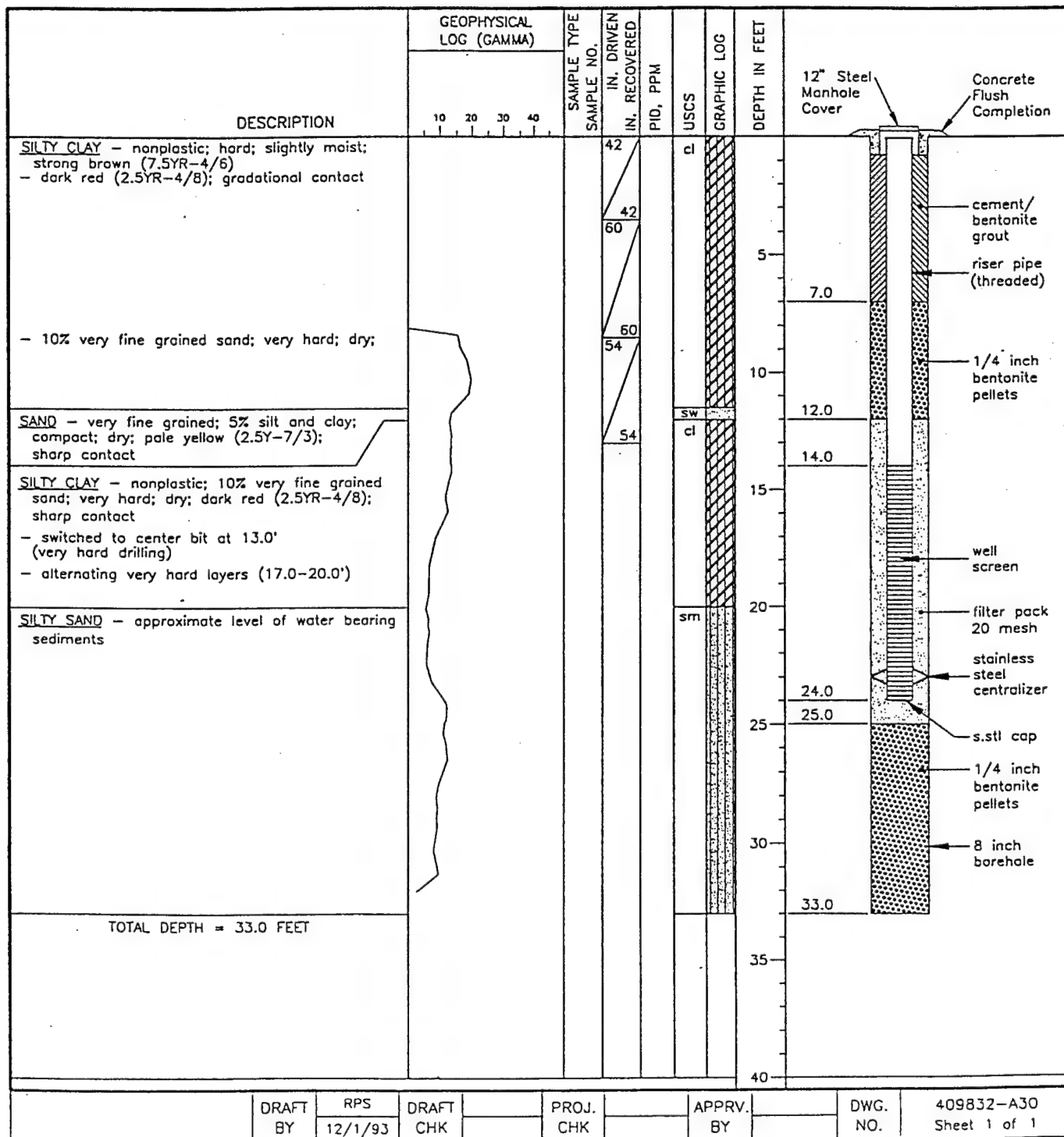
DRILLING AND SAMPLING INFORMATION

Boring Location: EAST OF SURFACE ELEV.(FT): 1245.940
FIRE TRAINING AREA TOTAL DEPTH(FT.): 33.0
Logged By: K. KIRSCHENMANN Date Started: 11/9/93
Drilled By: P. GUERREIN Date Completed: 11/9/93
GEOTECHNOLOGY, INC.
Drill Rig Type: CME-75
Drilling Method: 8" HOLLOW STEM AUGER
Sampling Method: 3"x5' CONTINUOUS SAMPLER

WELL COMPLETION DATA

Elev-Top of Casing(ft.): Ref. Datum: MSL
1. Riser Pipe-I.D.(in.): 2 Depth(ft.): 14 Type:S.Steel
Centralizers-Type: Depths(ft.):
2. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(ft.): 14-24 Slot Size(in.): .010
Centralizers-Type: S.Steel Depths(ft.):23
3. Filter Pack Type:Silica Sand Depth Interval(ft.):12-25
Conc. Pad Size: 4"x4"x6"

Notes: N 150444.517, E 2182140.558



Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-63B

DRILLING AND SAMPLING INFORMATION

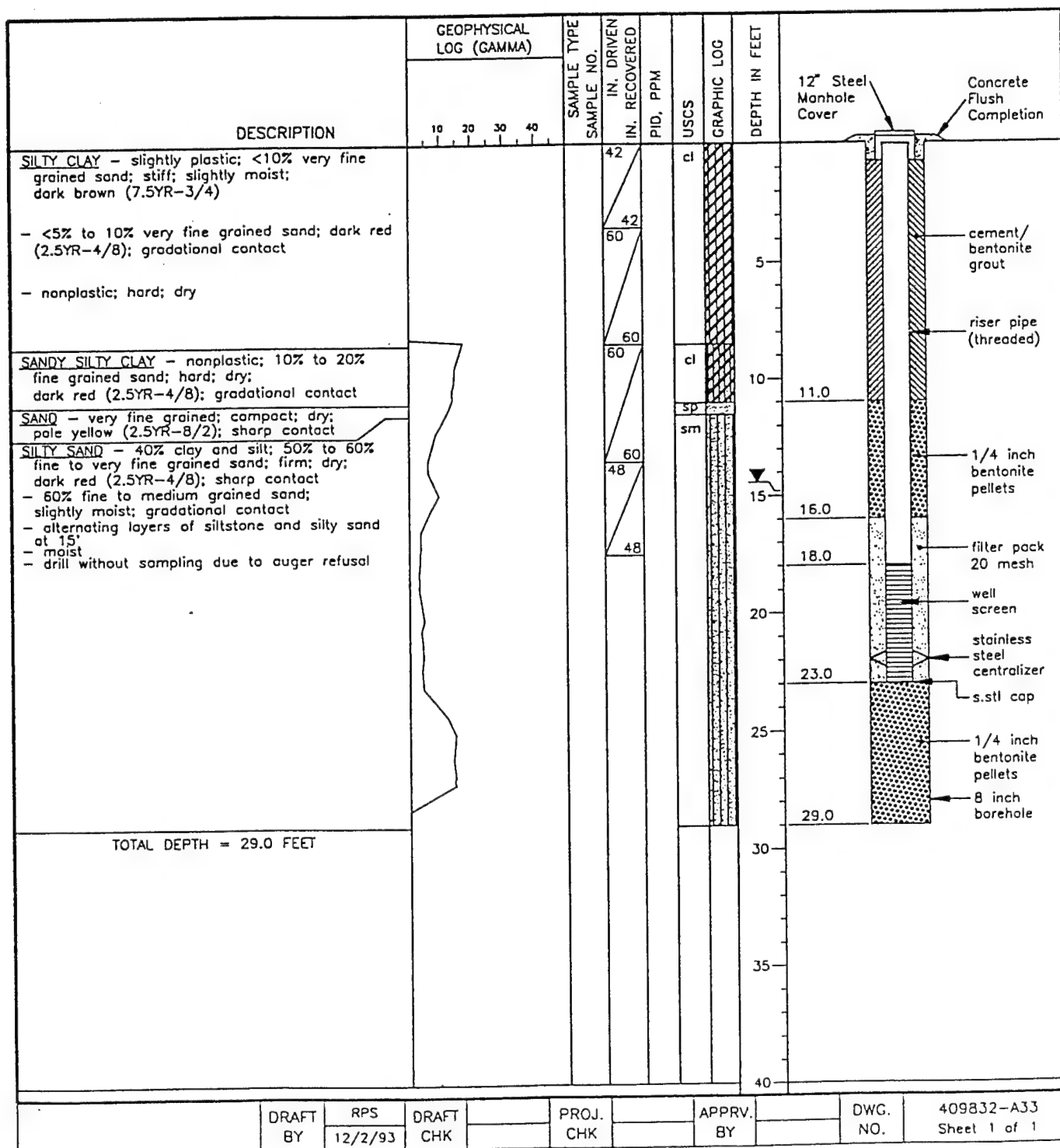
Boring Location: EAST OF FIRE TRAINING AREA
SURFACE ELEV.(FT.): 1243.284
TOTAL DEPTH(FT.): 29.0
Logged By: K. KIRSCHENMANN
Date Started: 11/8/93
Drilled By: P. GUERREIN
Date Completed: 11/8/93
GEOTECHNOLOGY, INC.
Drill Rig Type: CME-75
Drilling Method: 8" HOLLOW STEM AUGER
Sampling Method: 3"x5' CONTINUOUS SAMPLER

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
1. Riser Pipe-I.D.(in.): 2
Centralizers-Type:
2. Screen Dia.(in.): 2
Depth Interval(ft.): 18-23
Centralizers-Type: S.Steel
3. Filter Pack Type: Silica Sand
Conc. Pad Size: 4'x4'x6"

Ref. Datum: MSL
Depth(ft.): 18
Type: S.Steel
Depths(ft.):
Type: S.Steel Millslotted
Slot Size(in.): .010
Depths(ft.): 22
Depth Interval(ft.): 16-23

Notes: N 150386.113, E 2182035.358



DRAFT BY

RPS 12/2/93

DRAFT CHK

PROJ. CHK

APPRV. BY

DWG. NO.

409832-A33
Sheet 1 of 1

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-64B

DRILLING AND SAMPLING INFORMATION

WELL COMPLETION DATA

Boring Location: NORTHEAST OF SURFACE ELEV.(FT): 1245.586
FIRE TRAINING AREA TOTAL DEPTH(FT.): 33.0

Logged By: K. KIRSCHENMANN Date Started: 11/9/93
 Drilled By: P. GUERREIN Date Completed: 11/9/93

Drill Rig Type: CME-75
Drilling Method: 8" HOLLOW STEM AUGER

Sampling Method: 3"x5' CONTINUOUS SAMPLER

Elev-Top of Casing(ft.):

1. Riser Pipe-I.D.(in.): 2

Centralizers—Type:

2. Screen Dia.(in.): 2

Depth Interval(ft.): 16-26

Centralizers—Type: S.Steel

3. Filter Pack Type: Silica Sand

Conc. Pod Size: 4'x4'x6"

Ref. Datum: MSL

Depth(ft.): 16 Type:S.Steel

Depths(ft.):

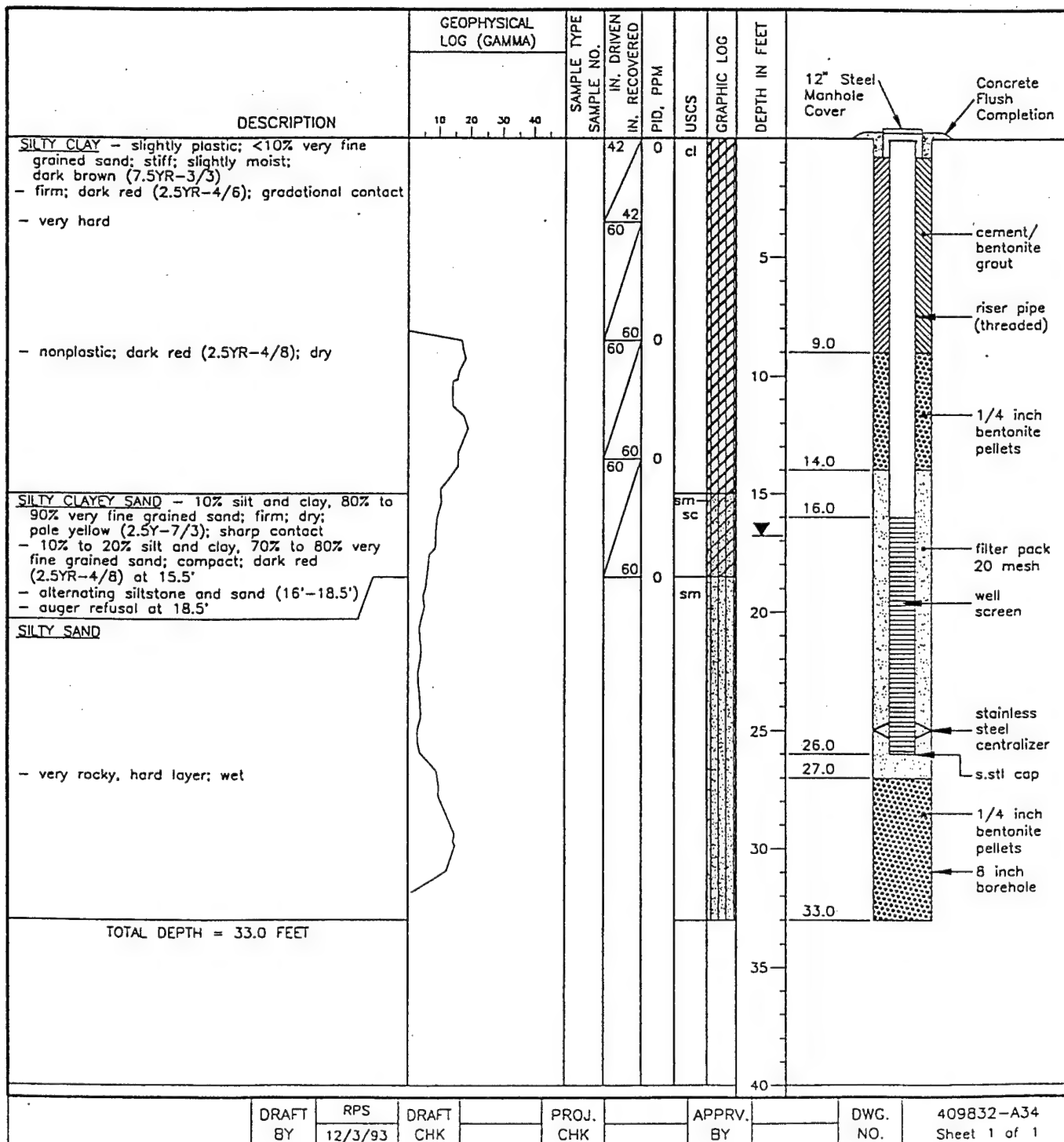
Type: S.Steel Millslotted

Slot Size(in.): .010

Depths(ft.): 25

Depth Interval(ft.): 14-27

Notes: N 150467.403, E 2181967.757



Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-65B

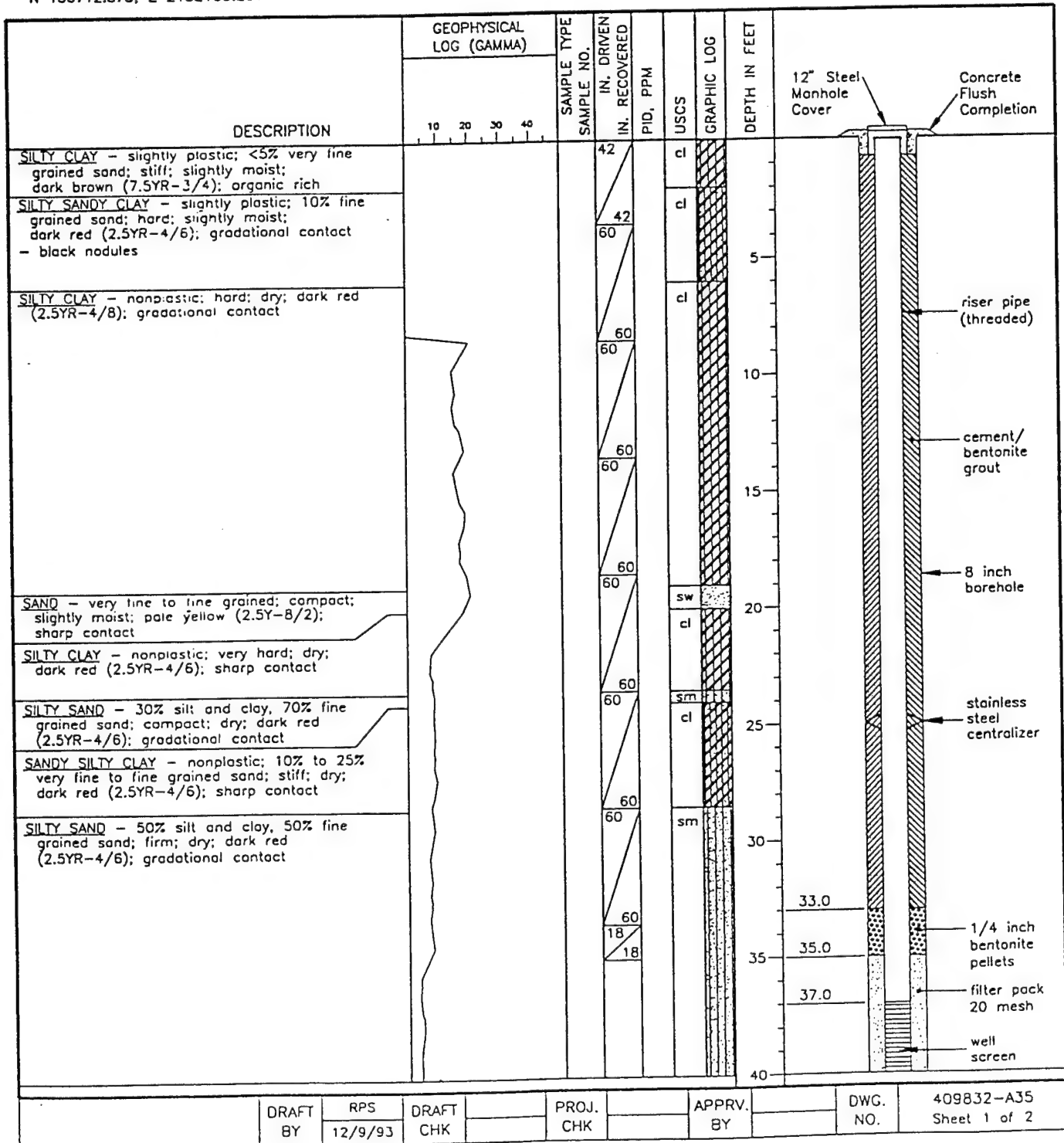
DRILLING AND SAMPLING INFORMATION

Boring Location: NORTHEAST OF FIRE TRAINING AREA
Surface Elev.(FT.): 1250.812
TOTAL DEPTH(FT.): 49.0
Logged By: K. KIRSCHENMANN Date Started: 11/5/93
Drilled By: P. GUERREIN Date Completed: 11/5/93
GEOTECHNOLOGY, INC.
Drill Rig Type: CME-75
Drilling Method: 8" HOLLOW STEM AUGER
Sampling Method: 3"x5' CONTINUOUS SAMPLER

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
1. Riser Pipe-I.D.(in.): 2
Centralizers-Type: S.Steel
2. Screen Dia.(in.): 2
Depth Interval(ft.): 37-47
Centralizers-Type: S.Steel
3. Filter Pack Type: Silica Sand
Conc. Pad Size: 4'x4'x6"
Ref. Datum: MSL
Depth(ft.): 37
Type: S.Steel
Depths(ft.): 25
Type: S.Steel Millslotted
Slot Size(in.): .010
Depths(ft.): 46
Depth Interval(ft.): 35-49

Notes: NO ANALYTICAL SAMPLES TAKEN
N 150712.875, E 2182183.201



Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-65B

DRILLING AND SAMPLING INFORMATION

Boring Location: NORTHEAST OF SURFACE ELEV.(FT): 1250.812
FIRE TRAINING AREA TOTAL DEPTH(FT.): 49.0

Logged By: K. KIRSCHENMANN Date Started: 11/5/93
 Drilled By: P. GUERREIN Date Completed: 11/5/93
 GEOTECHNOLOGY, INC.

Drill Rig Type: CME-75
Drilling Method: 8" HOLLOW STEM AUGER

Sampling Method: 3"x5' CONTINUOUS SAMPLER

WELL COMPLETION DATA

Elev-Top of Casing(ft.): Ref. Datum: MSL

1. Riser Pipe—I.D.(in.): 2	Depth(ft.): 37	Type:S.Steel
Centralizers—Type: S.Steel	Depths(ft.): 25	

2. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(ft.): 37-47 Slot Size(in.): .010

Centralizers—Type: S.Steel Depths(ft.): 46
3. Filter Pack Type: Silica Sand Depth Interval(ft.): 35–49
Conc. Pad Size: 4'x4'x6"

Notes: NO ANALYTICAL SAMPLES TAKEN
N 150712.875, E 2182183.201

DESCRIPTION	GEOPHYSICAL LOG (GAMMA)				SAMPLE TYPE SAMPLE NO.	IN. DRIVEN IN. RECOVERED	PID, PPM	USCS	GRAPHIC LOG	DEPTH IN FEET	
	10	20	30	40							
										45	
TOTAL DEPTH = 49.0 FEET										47.0	
										50	
										55	
										60	
										65	
										70	
										75	
										80	

filter pack
20 mesh

stainless
steel
centralizer

s.stl cop

DRAFT BY	RPS 12/9/93	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A35 Sheet 2 of 2
----------	----------------	-----------	--	-----------	--	-----------	--	----------	----------------------------

SITE FTA2 BORING NUMBER 2-167B

PROJECT TAFB Phase II RFI App. I Sites, Fire Train. Area 2

DATE DRILLED 07 August 1995 (Drilled as MWI)

DRILLING METHOD 6" Hollow-stem Augers; 5' Continuous Sampler

DRILLING COMPANY Associated Environmental Industries

ELEVATION 1247.70 Feet msl, Ground Surface; 1,250.74 Feet msl, TOC

TOTAL DEPTH 32 Feet

DEPTH TO WATER 14.8 Feet (open hole)

GEOLOGIST R. Osgood

X,Y COORD. 2182408.352, 150539.8117

SAMPLE				DEPTH feet	PTD (ppm)	MUNSELL	LITHOLOGY	GRAPHIC LOG	DESCRIPTION AND REMARKS
Analytical	Geotechnical	Interval	Recovery						
✗					ND	2.5YR4/4	OL		Topsoil, silty, w/vegetation and subrounded, pebble-sized clasts.
					ND	2.5YR4/6			Clayey silt, reddish brown, soft, slightly moist, low plasticity, some black organic speckling throughout.
				5	ND	2.5YR4/6			At 4 ft, grades to silt, red, firm, dry, a few small subrounded pebbles; light grey marbling at base.
✗					ND	2.5YR4/4	ML CL		Clayey silt, reddish brown, firm, dry, some black organic speckling, and trace of light grey marbling (mineralization?).
				10	ND	2.5YR4/6			Clayey silt, red, firm, dry, massive (homogeneous).
✗									No Recovery
				15	ND	2.5YR4/6	ML		Silt, light grey, stiff, moist for top 1". Interval grades from silt to sandy silt, red, moist, soft, massive. At 12 ft, moderately cemented sandstone clasts appx. 1" in diameter.
✗					ND				No Recovery
				20	ND	2.5YR4/6	ML		Sandy silt (appx 75% silt), red, soft, very moist, few 1" moderately cemented sandstone fragments; lens of fine sand appx. 1" thick at 21.5 ft.
✗					ND				No Recovery
				25			SM		

SITE FTA2 BORING NUMBER 2-167B

PROJECT TAFB Phase II RFI App. I Sites, Fire Train. Area 2

DATE DRILLED 07 August 1995 (Drilled as MWI)

DRILLING METHOD 6" Hollow-stem Augers; 5' Continuous Sampler

DRILLING COMPANY Associated Environmental Industries

ELEVATION 1247.70 Feet msl, Ground Surface; 1,250.74 Feet msl, TOC

TOTAL DEPTH 32 Feet

DEPTH TO WATER 14.8 Feet (open hole)

GEOLOGIST R. Osgood

X,Y COORD. 2182408.352, 150539.8117

SAMPLE				DEPTH feet	PID (ppm)	MUNSELL	LITHOLOGY	GRAPHIC LOG	DESCRIPTION AND REMARKS
Analytical	Geotechnical	Interval	Recovery						
<input checked="" type="checkbox"/>					ND	2.5YR4/4	SM		Silty sand (60%), reddish brown, soft, wet, very fine sand laminated throughout.
									No Recovery
<input checked="" type="checkbox"/>				30			SP		Sand, red, fine grained, poorly graded, wet, homogeneous color and massive texture.
									Completed as monitoring well 2-187 on 07 August 1995.
				35					
				40					
				45					
				50					

Tetra Tech Monitoring Well Construction Log

Project/Site Name: <u>TAFB Phase II RFI, FTA2</u>	Well No: <u>2-167 B</u>	Date: <u>08 Aug 95</u>
Project No: <u>7107</u>	Drilling Method: <u>8-3/4" Hollow-stem Augers</u>	
Geologist: <u>R. Osgood</u>		
Elevation of Casing: <u>1250.7 Ft msl</u>	Drilling Contractor: <u>Associated Environmental Industries</u>	
Surface Elevation: <u>1247.7 Ft msl</u>	Date Well Construction Completed: <u>08 Aug 95</u>	

Type of Protective Casing: Steel
 Dimensions: 6"x6"x60"
 Height of Stickup: 2.8 ft
 Weep Hole: Y/N Cap Vent: Y/N Locking Cap: Y/N

Type of Surface Grout: Concrete to appx. 4 ft bgs.

Surface Casing(s) Diameter/Type/Length: Not Applicable
 Surface Casing Grouting Information: Not Applicable

Riser Length Above Screen: 21.8 ft
 Riser Inner Diameter/Type: 4" diameter
Schedule 304 Stainless Steel

Boring Diameter(s): 8-3/4"

Type of Annular Seal: Portland Type I, 2% Bentonite

Depth to Bentonite Seal: 12 ft
 Type of Bentonite: Medium Chips
 Length of Seal: 5 ft

Depth to Top of Filter Pack: 17 ft
 Type of Filter Pack: 10/20 Sand

Depth to Screen: 19 ft
 Screen Length and Type: 10 ft, 4" diameter
Schedule 304 Stainless Steel
 Slot Size: 0.010"
 Screened Interval: 19 to 29 ft

Length of Sediment Sump: 3 ft
 Diameter/Type of Sediment Sump: 4" diameter Sch. 304 Stainless Steel

Original Boring Depth: 32 ft
 Top of Bentonite Plug: 30 ft
 Type of Backfill: Bentonite Chips

Centralizers: At appx. 18 ft and 30 ft.

SITE FTA2 BORING NUMBER 2-168B

PROJECT TAFB Phase II RFI App. I Sites, Fire Train. Area 2
 DATE DRILLED 08 August 1995 (Drilled as MW2)
 DRILLING METHOD 6" Hollow-stem Augers; 5' Continuous Sampler
 DRILLING COMPANY Associated Environmental Industries
 ELEVATION 1240.10 Feet msl, Ground Surface; 1,243.00 Feet msl, TOC
 TOTAL DEPTH 25 Feet
 DEPTH TO WATER 10.6 Feet bgs
 GEOLOGIST R. Osgood
 X,Y COORD. 2181976.691, 150248.99500

SAMPLE				DEPTH feet	PID (ppm)	MUNSELL	LITHOLOGY	GRAPHIC LOG	DESCRIPTION AND REMARKS
Analytical	Geotechnical	Interval	Recovery						
					ND	2.5YR3/4			Topsoil, clayey silt, dark reddish brown, soft, slightly moist, root hairs extend to 1.5 ft. Clayey silt stiffens to base of core with trace of organic speckling from 2 to 5 ft.
				15					
				ND					
				5					
				1.0		2.5YR4/4	CL		Clayey silt, reddish brown, soft to firm, slightly moist, massive, some black organic speckling and small nodules. From 7 to 10 ft, some subangular pebbles and increase in the amount of black organics.
				ND					
				10					Clayey silt as above to 10.8 ft.
				21		2.5YR4/4	ML		Sandy silt, red, soft, moist to saturated at 13 ft, thin bedding (laminated), black organics from 11.5 to 12 ft.
				4/6		2.5YR4/6			No Recovery
				15					
				20		2.5YR4/6	SM		Silty sand, red, wet, laminated layers (2-5 mm). From 17 to 17.5 ft, dark black organic lens with small (<3 mm) nodules. Some black speckles of organic matter to 19 ft.
				3					
				1					
				20					No Recovery
				21		2.5YR4/6	SM		Silty sand, red, wet, laminated (appx. 2 mm), trace of black organic speckling throughout.
									No Recovery
				25					

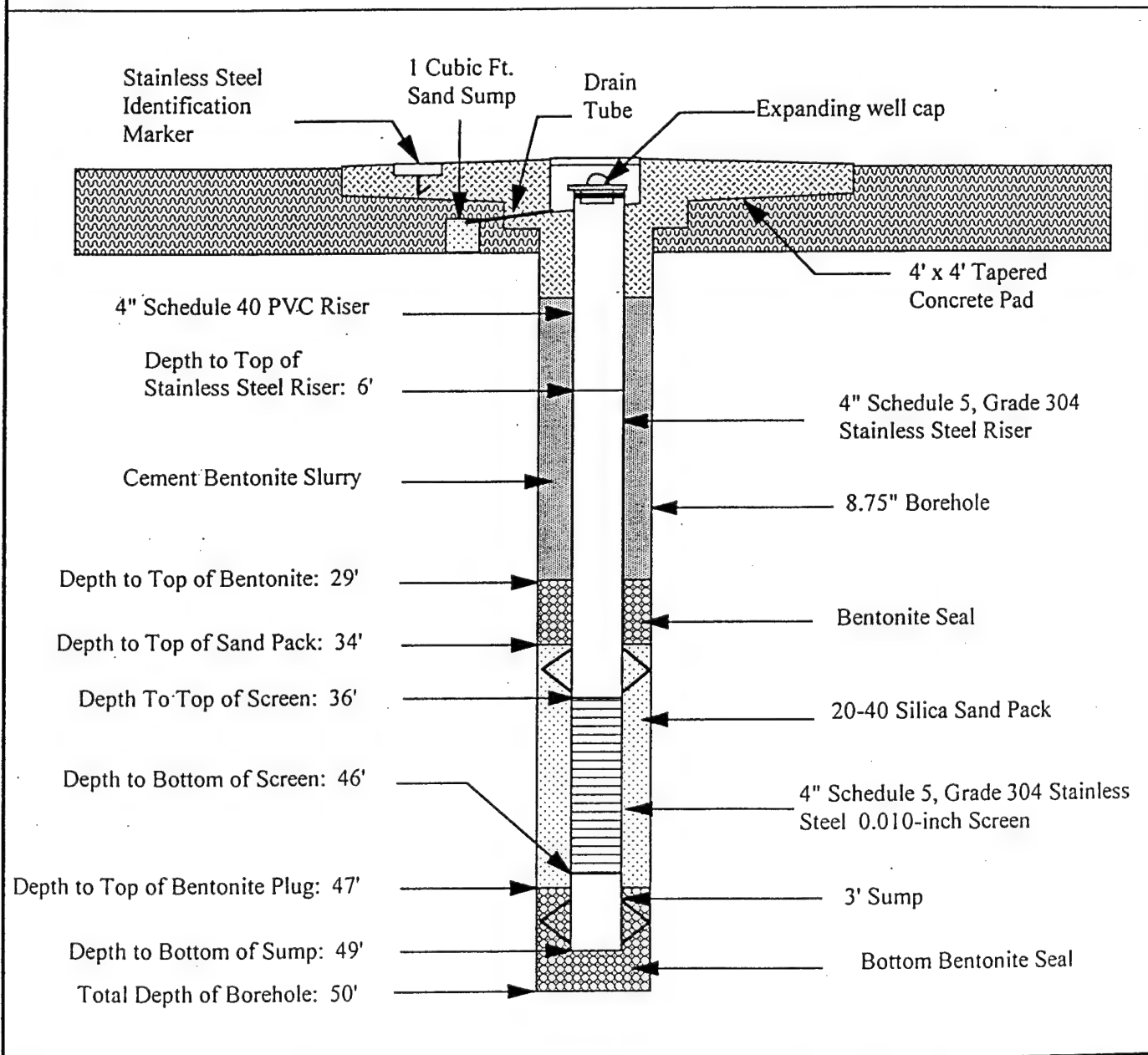
Tetra Tech Monitoring Well Construction Log

Project/Site Name: <u>TAFB Phase II RFI, FTA2</u>	Well No: <u>2-168 B</u>	Date: <u>08 Aug 95</u>
Project No: <u>7107</u>	Drilling Method: <u>8-3/4" Hollow-stem Augers</u>	
Geologist: <u>R. Osgood</u>		
Elevation of Casing: <u>1243.0 Ft msl</u>	Drilling Contractor: <u>Associated Environmental Industries</u>	
Surface Elevation: <u>1240.1 Ft msl</u>	Date Well Construction Completed: <u>08 Aug 95</u>	

	<p>Type of Protective Casing: <u>Steel</u> Dimensions: <u>6"x6"x60"</u> Height of Stickup: <u>2.8 ft</u> Weep Hole: <u>Y/N</u> Cap Vent: <u>Y/N</u> Locking Cap: <u>Y/N</u></p> <p>Type of Surface Grout: <u>Concrete to appx. 4 ft bgs</u></p> <p>Surface Casing(s) Diameter/Type/Length: <u>Not Applicable</u> Surface Casing Grouting Information: <u>Not Applicable</u></p> <p>Riser Length Above Screen: <u>12.8 ft</u> Riser Inner Diameter/Type: <u>4" diameter</u> <u>Schedule 304 Stainless Steel</u></p> <p>Boring Diameter(s): <u>8-3/4"</u></p> <p>Type of Annular Seal: <u>Portland Type I, 2% Bentonite</u></p> <p>Depth to Bentonite Seal: <u>7 ft</u> Type of Bentonite: <u>Medium Chips</u> Length of Seal: <u>2 ft</u></p> <p>Depth to Top of Filter Pack: <u>9 ft</u> Type of Filter Pack: <u>10/20 Sand</u></p> <p>Depth to Screen: <u>10 ft</u> Screen Length and Type: <u>10 ft, 4" diameter</u> <u>Schedule 304 Stainless Steel</u> Slot Size: <u>0.010"</u> Screened Interval: <u>10 to 20 ft</u></p> <p>Length of Sediment Sump: <u>3 ft</u> Diameter/Type of Sediment Sump: <u>4" diameter Sch. 304 Stainless Steel</u></p> <p>Original Boring Depth: <u>25 ft</u> Top of Bentonite Plug: <u>23 ft</u> Type of Backfill: <u>Bentonite Chips</u></p> <p>Centralizers: <u>At appx. 9.5 ft and 21.5 ft</u></p>
--	---

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-271B
Location: TAFB, Oklahoma	Site: FT22
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 08/08/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,252.41'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,252.13'
Project Geologist: Steve Kelly	Northing Coordinate: 151,494.42'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,182,196.43'
Drilling Method: Hollow Stem Auger	Permanent Monuments Used in Survey: SE32, SE28
Dedicated Pump: 2-inch Grundfos	Legal Description: NE/4 Section 22, T11N, R2W
Comments:	

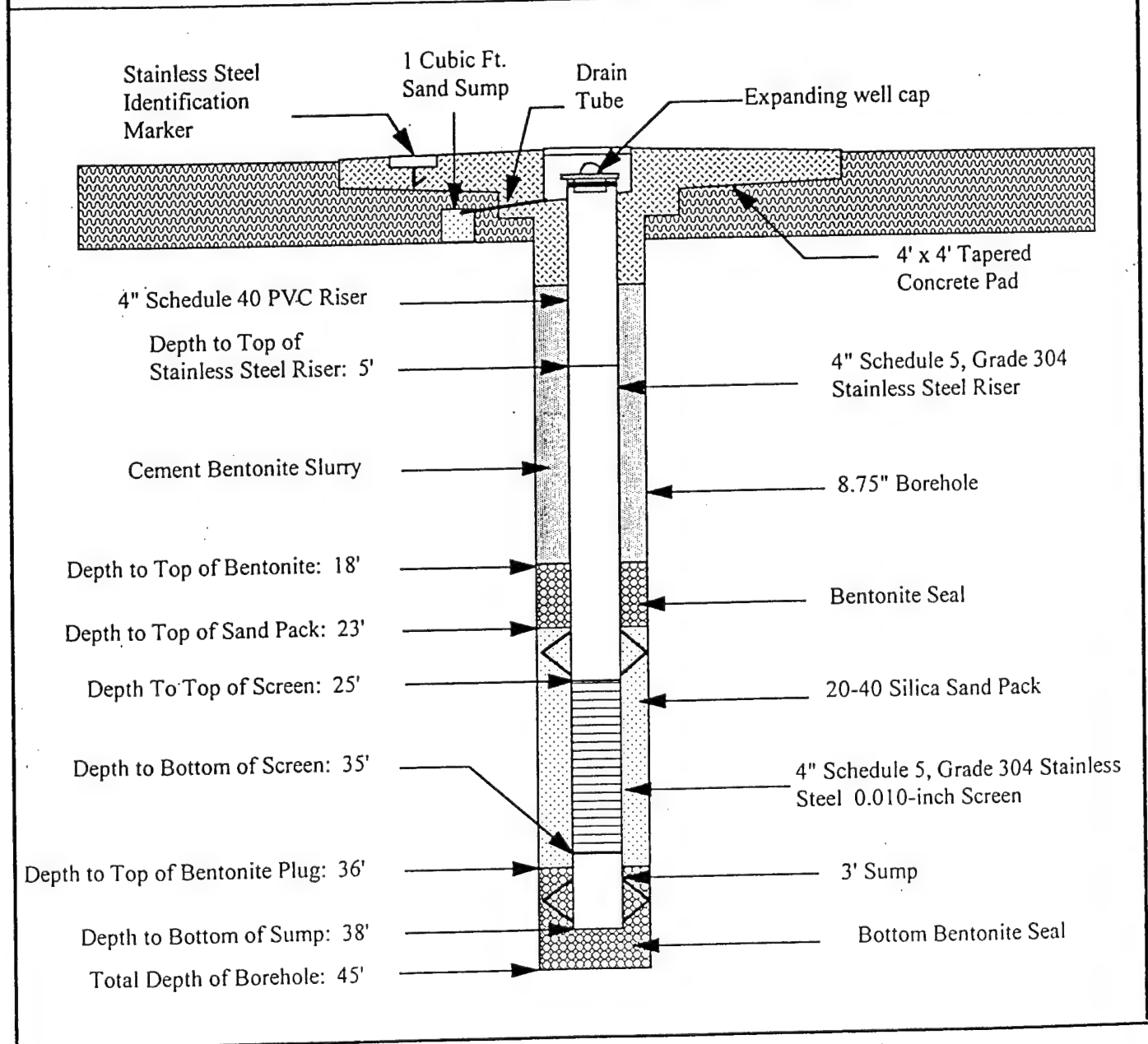


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-272B
Location: TAFB, Oklahoma	Site: FT22
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 08/09/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,249.38'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,248.91'
Project Geologist: Steve Kelly	Northing Coordinate: 150,784.70'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,181,581.74'
Drilling Method: Hollow Stem Auger	Permanent Monuments Used in Survey: SE32, SE28
Dedicated Pump: 2-inch Grundfos	Legal Description: SE/4 Section 22, T11N, R2W
Comments: Ground Level Elevation measured on identification plate rather than surveyor's pin.	

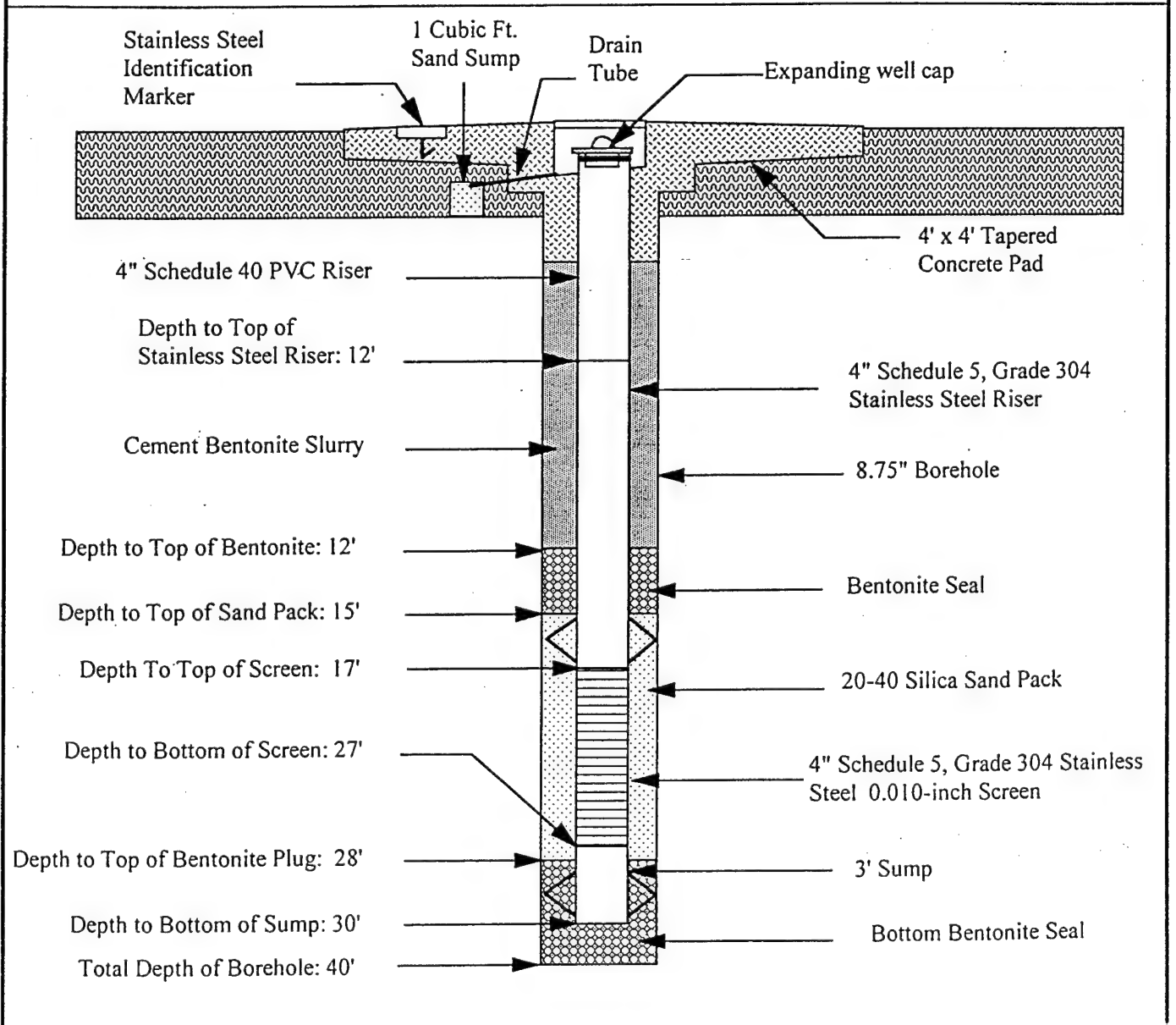


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-273B
Location: TAFB, Oklahoma	Site: FT22
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 06/18/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,238.92'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,238.42'
Project Geologist: Steve Kelly	Northing Coordinate: 150,351.11'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,181,576.36'
Drilling Method: Hollow Stem Auger	Permanent Monuments Used in Survey: SE32, SE28
Dedicated Pump: 2-inch Grundfos	Legal Description: SE/4 Section 22, T11N, R2W
Comments: Ground Level Elevation measured on identification plate rather than surveyor's pin. 3' thick top bentonite seal set.	

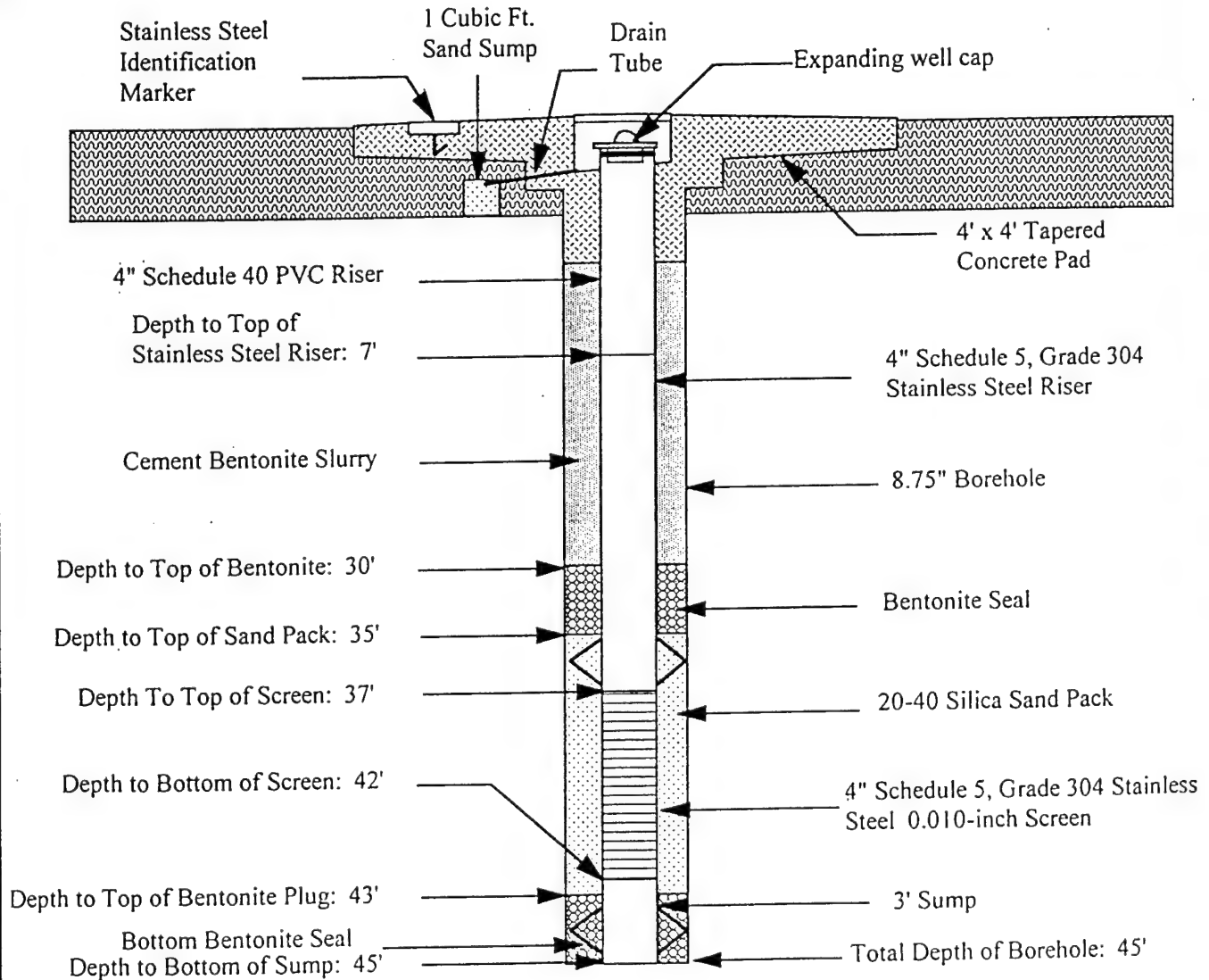


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-274B
Location: TAFB, Oklahoma	Site: FT22
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 07/25/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,248.77'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,248.32'
Project Geologist: Steve Kelly	Northing Coordinate: 151,126.23'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,181,625.92'
Drilling Method: Hollow Stem Auger	Permanent Monuments Used in Survey: SE32, SE28
Dedicated Pump: 2-inch Grundfos	Legal Description: NE/4 Section 22 T11N, R2W
Comments: 5' long screen set. Well set at bottom of borehole. Ground Level Elevation measured on identification plate rather than surveyor's pin.	



Drawing not to scale

< > Centralizers

5/22/93

MW 1-67B

RISER	0-34
SCREEN	34-44
SAND PACK	32-44
BENTONITE	30-32
GROUT	0-30

MW 1-67A

10" SURFACE CASING	0-46
RISER	0-75
SCREEN	75-85
SAND PACK	73-85
BENTONITE	71-73
GROUT	0-71

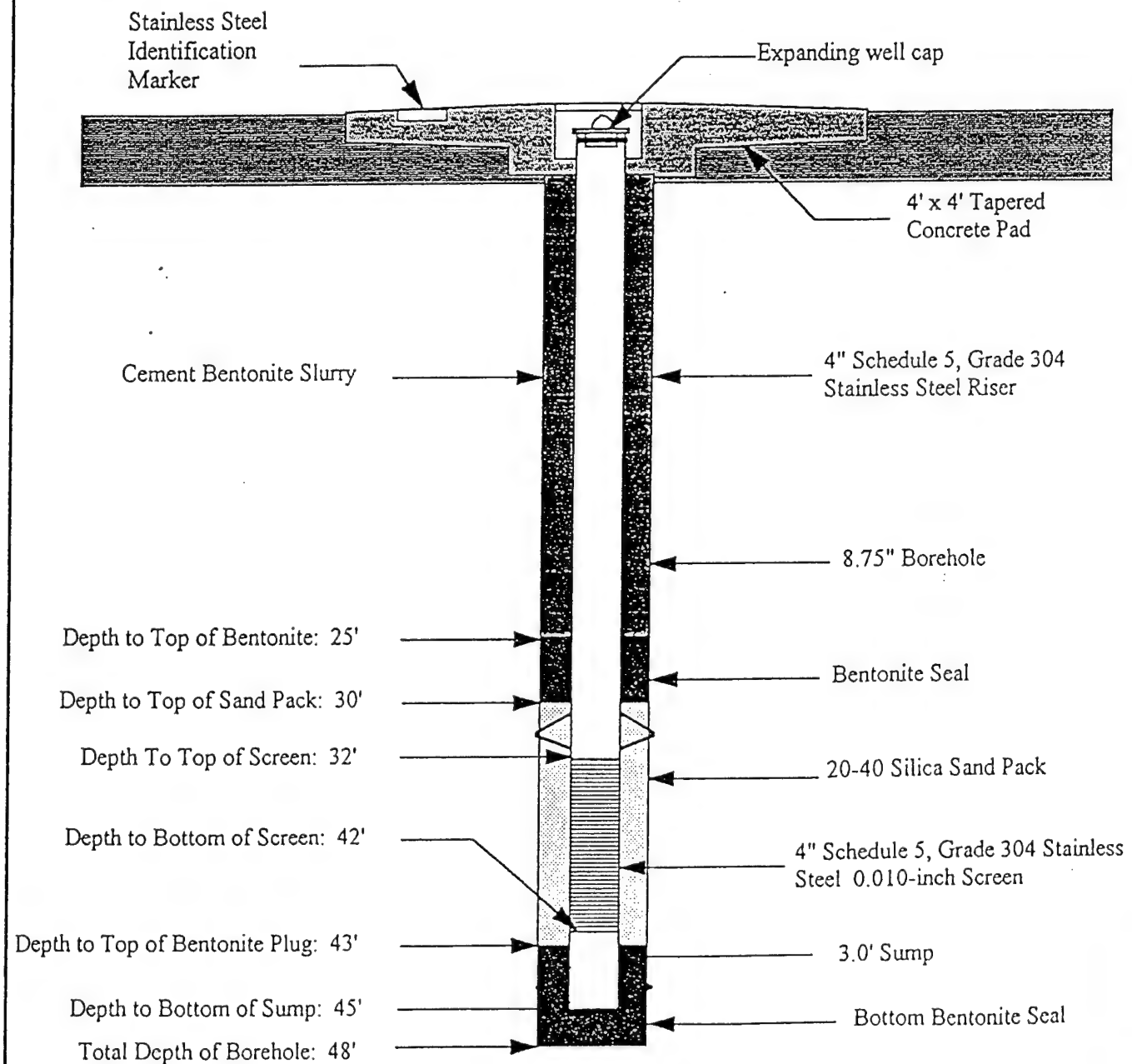
MW 1-67C

16" SURFACE CASING	0-46
10" CASING	0-90
RISER	0-109
SCREEN	109-119
SAND PACK	107-119
BENTONITE	105-107
GROUT	0-105

MW 1-67 WELL COMPLETION INFO.

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-142B
Location: TAFB, Oklahoma	Site: BW
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/19/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1242.45'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1242.09'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	

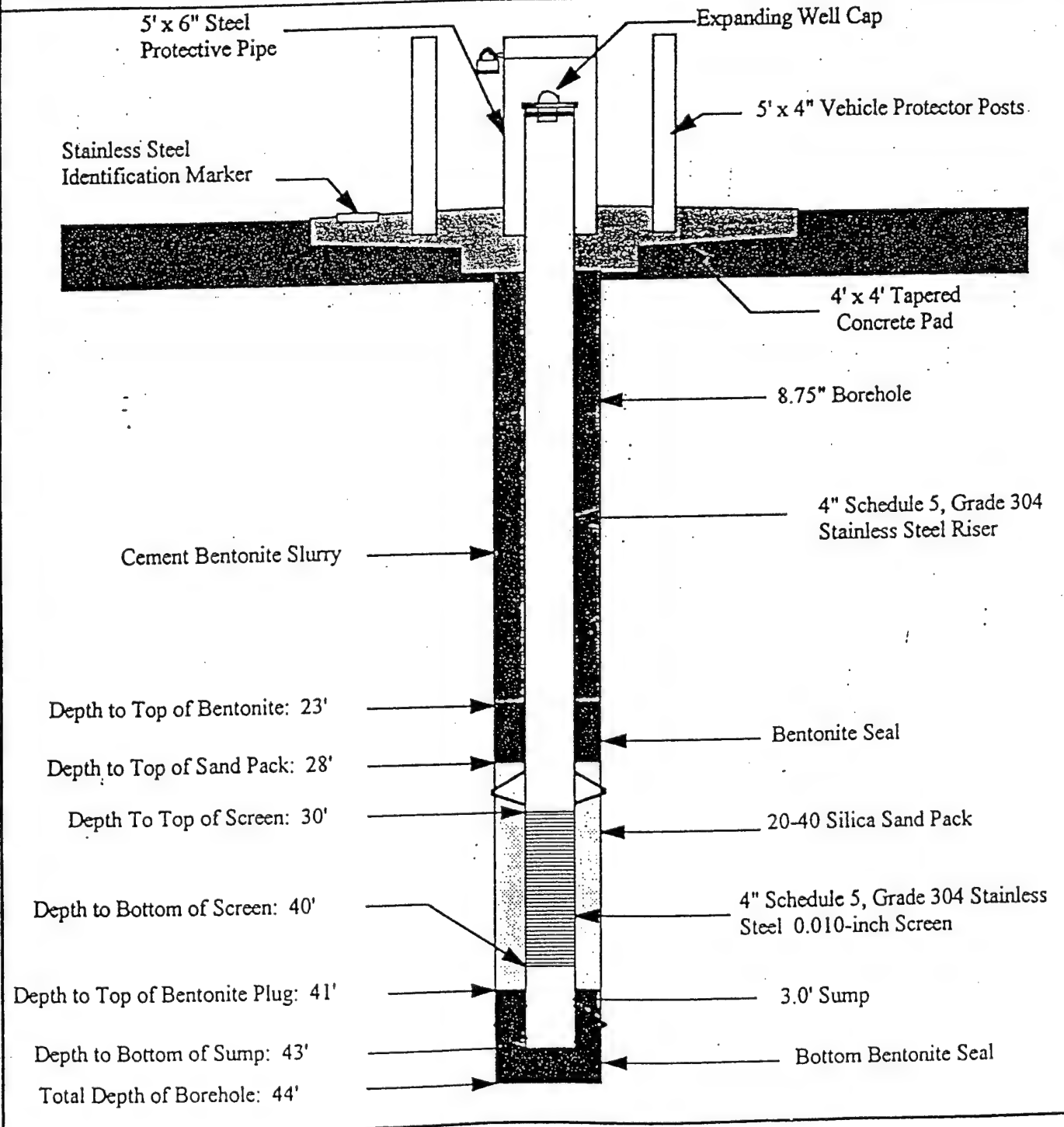


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-112B
Location: TAFB, Oklahoma	Site: LF15
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 1/20/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1250.89'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1247.65'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser : 4" Schedule 40 PVC Casing.	

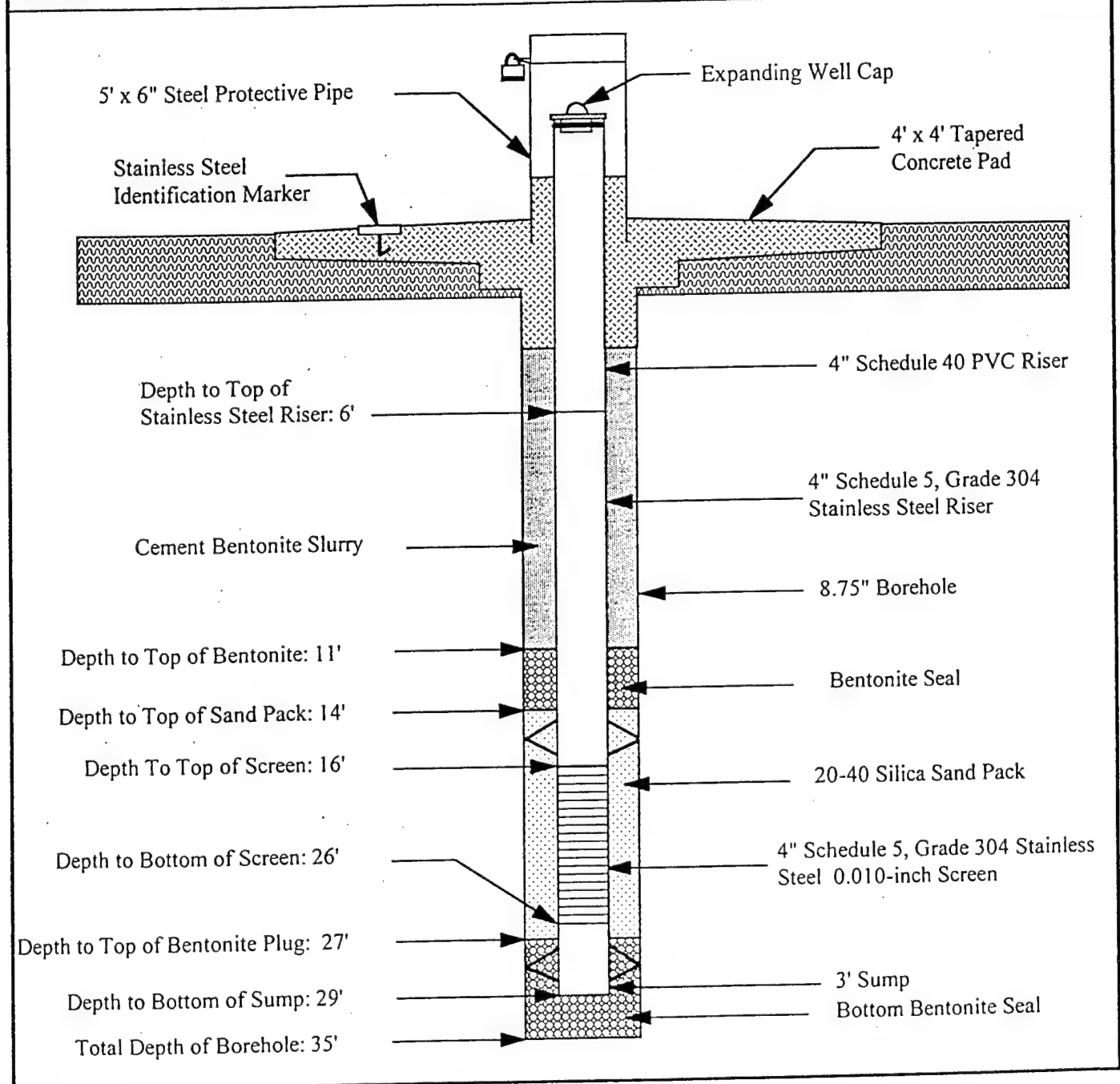


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-301B
Location: TAFB, Oklahoma	Site: LF15
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 06/17/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,263.19'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,265.71'
Project Geologist: Steve Kelly	Northing Coordinate: 150,500.39'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,176,072.65'
Drilling Method: Hollow Stem Auger	Permanent Monuments used in Survey: SE40, PR15
Dedicated Pump: 2-inch Grundfos	Legal Description: SW/4 Section 23, T11N, R2W
Comments: 3' thick top bentonite seal set.	



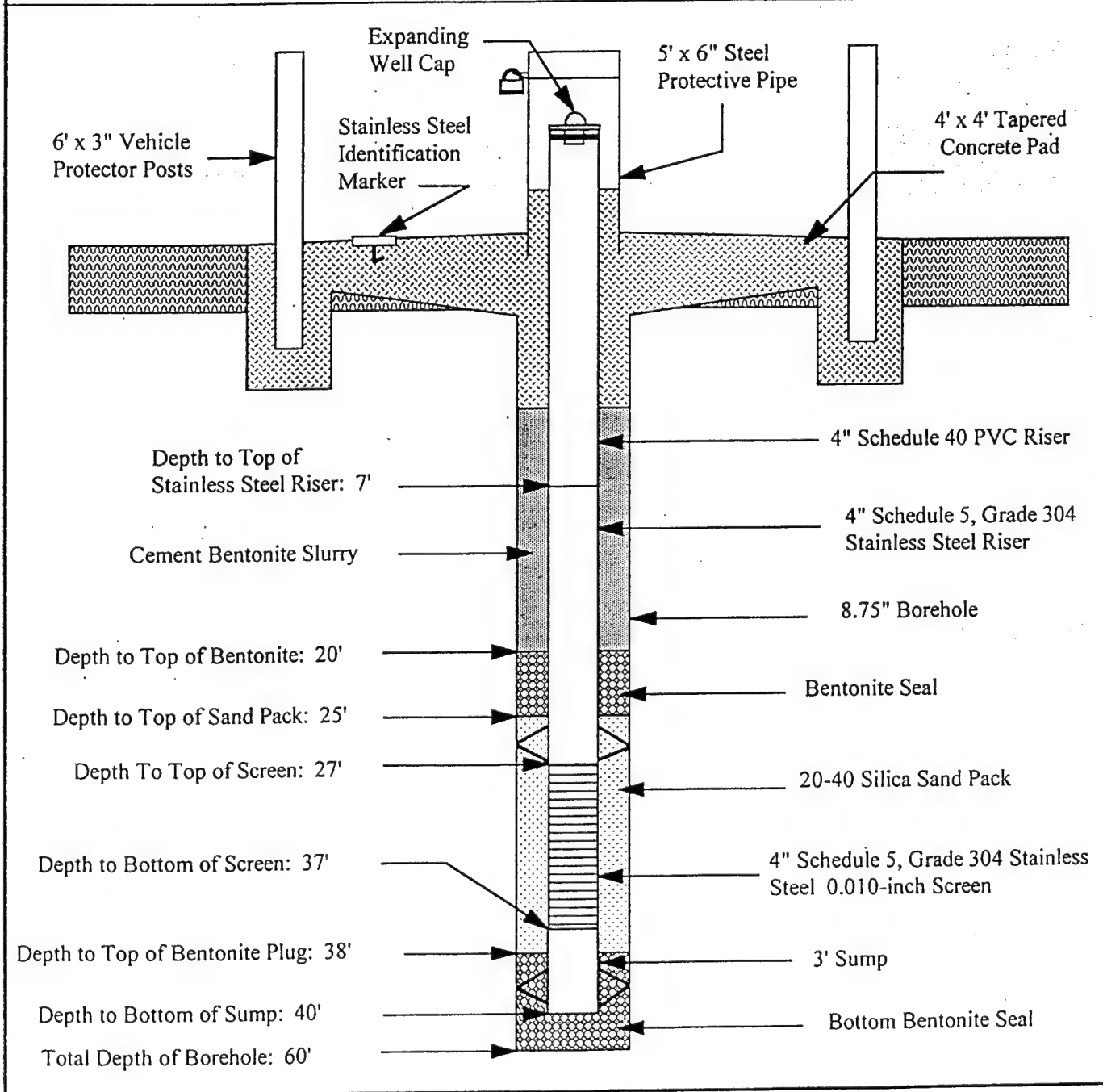
Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-302B
Location: TAFB, Oklahoma	Site: LF15
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 07/24/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,246.46'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,249.15'
Project Geologist: Steve Kelly	Northing Coordinate: 149,491.80'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,182,106.79'
Drilling Method: Hollow Stem Auger	Permanent Monuments used in Survey: SE32, SE28
Dedicated Pump: 2-inch Grundfos	Legal Description: SE/4 Section 22, T11N, R2W

Comments:

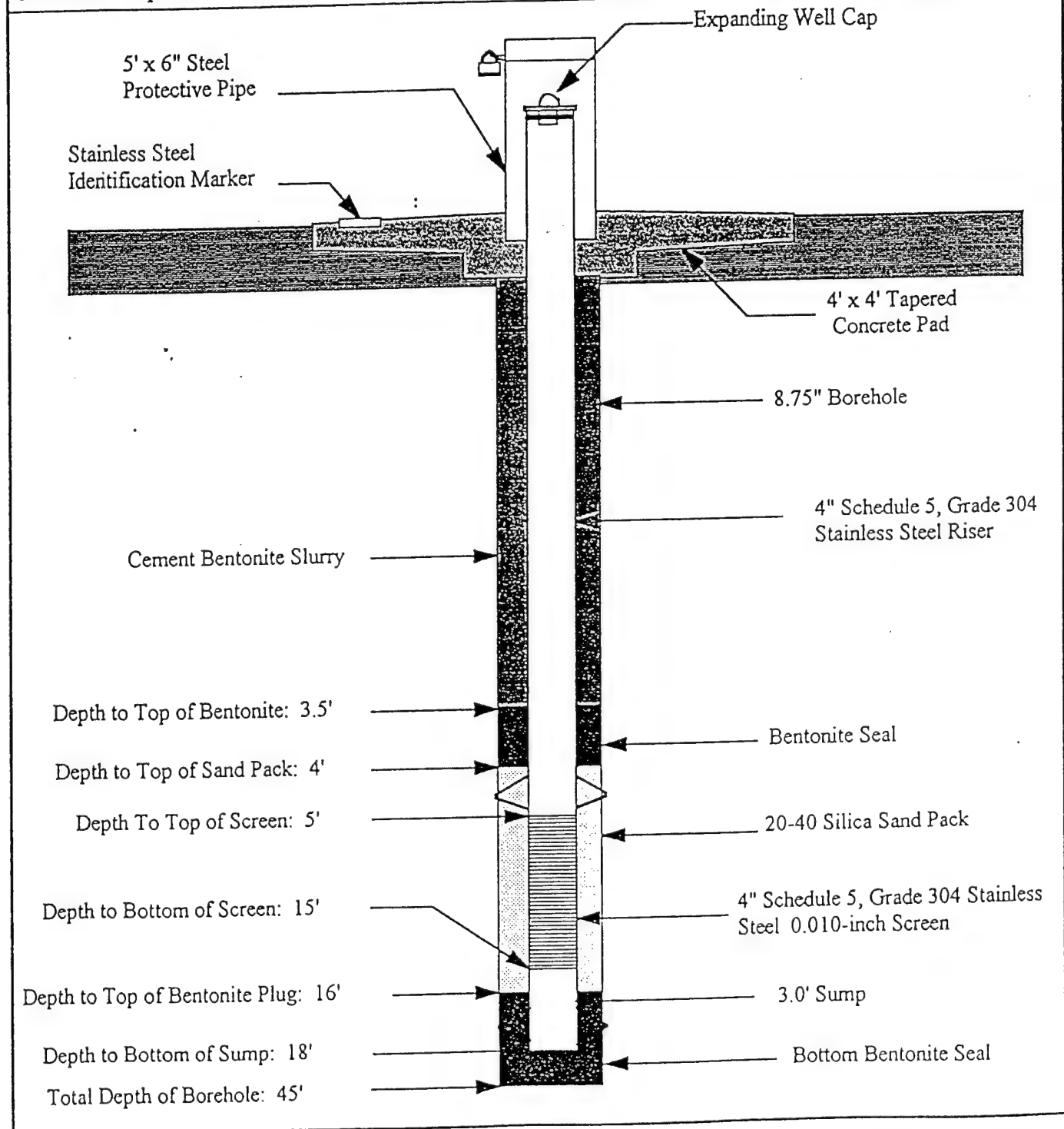


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-160B
Location: TAFB, Oklahoma	Site: ST07
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/05/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1250.99'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1253.56'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing. 6" thick top bentonite seal set. Sand set 1' above screen.	



Drawing not to scale

< > Centralizers

Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-62A

DRILLING AND SAMPLING INFORMATION

Boring Location: EAST SIDE OF FIRE TRAINING AREA 2
Logged By: M. WILSON
Drilled By: D. MEYER

SURFACE ELEV.(FT): 1246.213
TOTAL DEPTH(FT.): 70
Date Started: 11/22/93
Date Completed: 11/29/93

GEOTECHNOLOGY, INC.

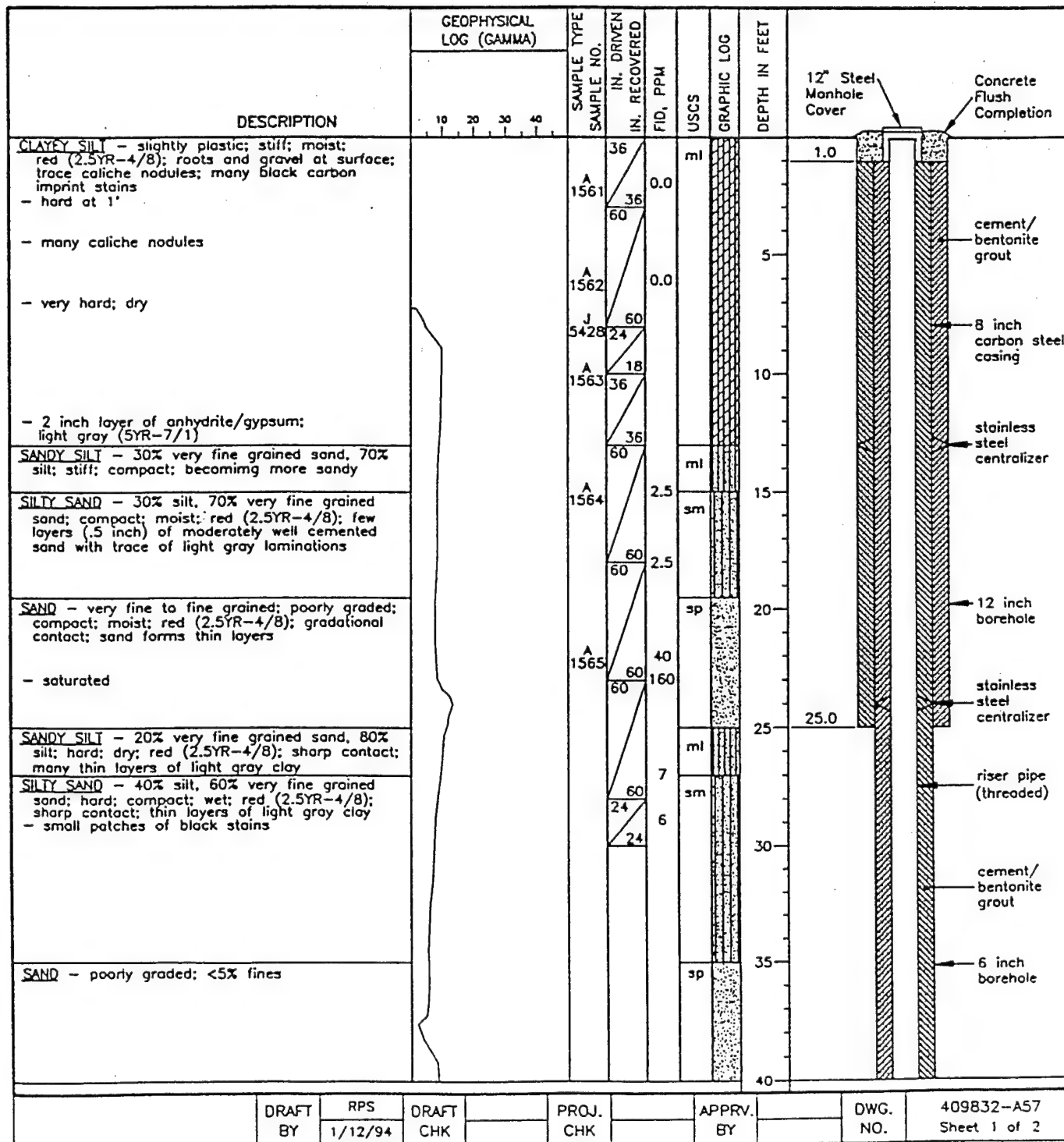
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS
AND MUD ROTARY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5" CONTINUOUS SAMPLER

Notes: N 150447.890, E 2182152.166

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
1. Surf Casing-I.D.(in.): 8
Centralizers-Type: S.Steel
2. Riser Pipe-I.D.(in.): 2
Centralizers-Type: S.Steel
3. Screen Dia.(in.): 2
Depth Interval(ft.): 53.8-63.7
Centralizers-Type:
4. Filter Pack Type: Silica Sand
Conc. Pod Size: 4"x4"x6"

Ref. Datum: MSL
Depth(ft.): 25 Type: Carbon Steel
Depths(ft.): 13
Depth(ft.): 53.8 Type: S.Steel
Depths(ft.): 24, 53
Type: S.Steel Wire Wound
Slot Size(in.): .010
Depths(ft.):
Depth Interval(ft.): 52.0-65.0



Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-62A

DRILLING AND SAMPLING INFORMATION

Boring Location: EAST SIDE OF FIRE TRAINING AREA 2
Logged By: M. WILSON
Drilled By: D. MEYER
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS AND MUD ROTARY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5" CONTINUOUS SAMPLER

SURFACE ELEV.(FT): 1246.213
TOTAL DEPTH(FT.): 70
Date Started: 11/22/93
Date Completed: 11/29/93

GEOTECHNOLOGY, INC.

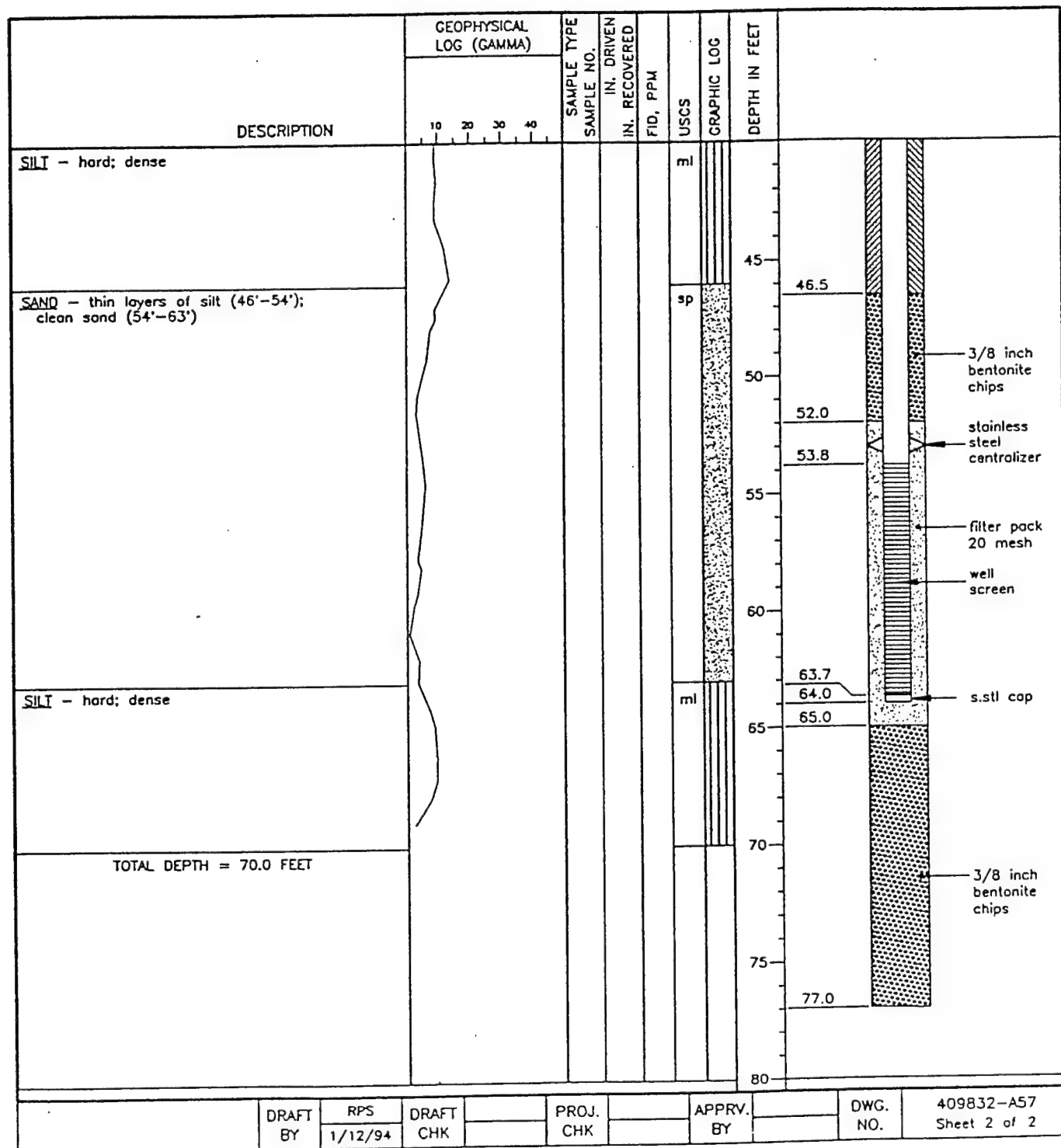
WELL COMPLETION DATA

Elev-Top of Casing(ft.):
1. Surf Casing-I.D.(in.): 8
Centralizers-Type: S.Steel
2. Riser Pipe-I.D.(in.): 2
Centralizers-Type: S.Steel
3. Screen Dia.(in.): 2
Depth Interval(ft.): 53.8-63.7
Centralizers-Type:
4. Filter Pack Type: Silica Sand
Conc. Pad Size: 4"x4"x6"

Ref. Datum: MSL

Depth(ft.): 25 Type: Carbon Steel
Depths(ft.): 13
Depth(ft.): 53.8 Type: S.Steel
Depths(ft.): 24, 53
Type: S.Steel Wire Wound
Slot Size(in.): .010
Depths(ft.):
Depth Interval(ft.): 52.0-65.0

Notes: N 150447.890, E 2182152.166



Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

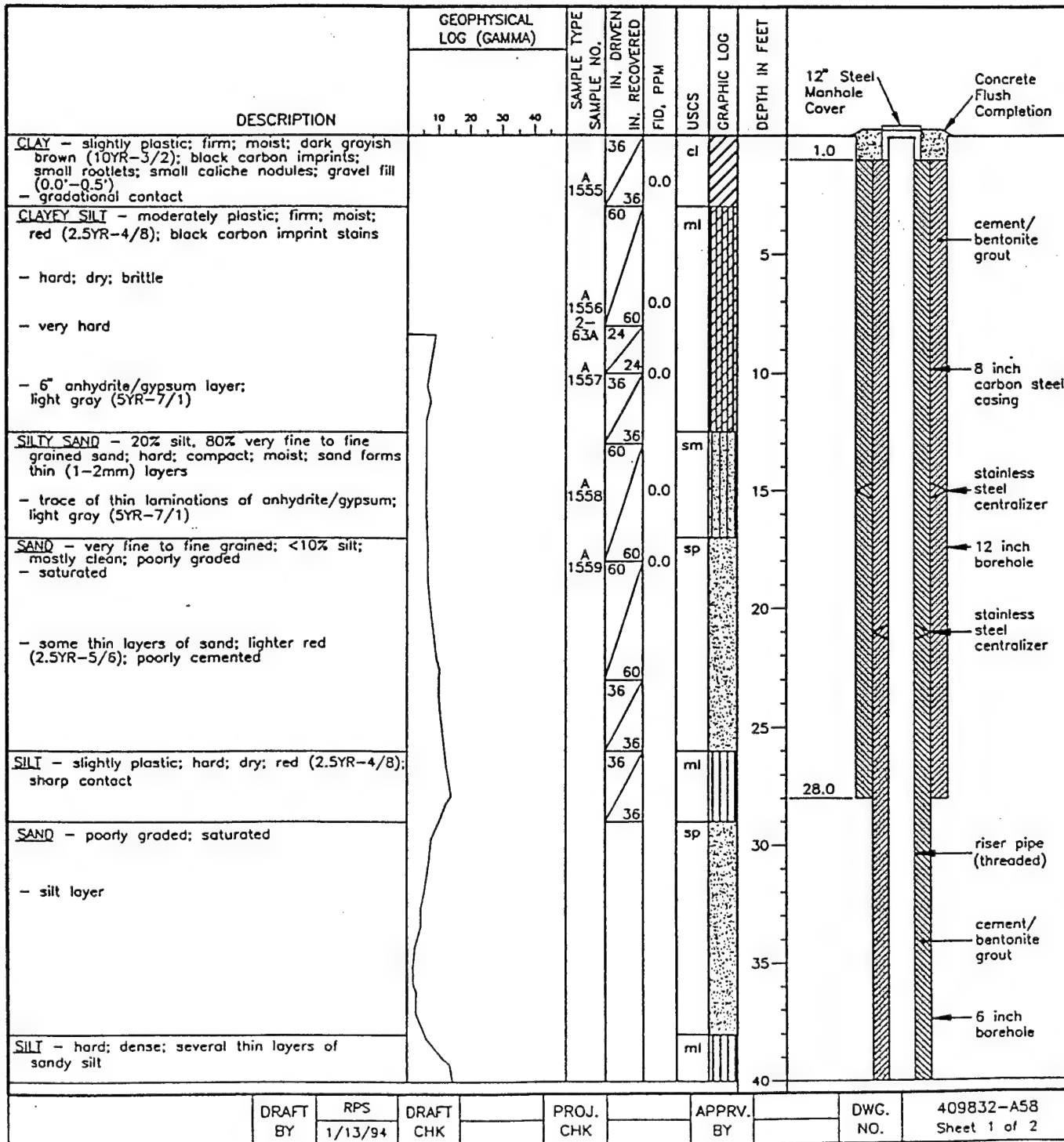
MONITORING WELL 2-63A

DRILLING AND SAMPLING INFORMATION

Boring Location: EAST SIDE OF SURFACE ELEV.(FT): 1243.387
FIRE TRAINING AREA 2 TOTAL DEPTH(FT.): 67
Logged By: M. WILSON Date Started: 11/19/93
Drilled By: D. MEYER Date Completed: 11/23/93
GEOTECHNOLOGY. INC.
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS
AND MUD ROTORY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5' CONTINUOUS SAMPLER
AND 1-1/2"x2' SPLIT SPOON
Notes: N 150389.964, E 2182043.019

WELL COMPLETION DATA

Elev-Top of Casing(ft.): Ref. Datum:MSL
1. Surf Casing-I.D.(in.):8 Depth(ft.): 28 Type: Carbon Steel
Centralizers-Type: S.Steel Depths(ft.): 15
2. Riser Pipe-I.D.(in.): 2 Depth(ft.): 53 Type: S.Steel
Centralizers-Type: S.Steel Depths(ft.): 21, 51
3. Screen Dia.(in.): 2 Type: S.Steel Wire Wound
Depth Interval(ft.):53.0-63.0 Slot Size(in.): .010
Centralizers-Type: Depths(ft.):
4. Filter Pack Type:Silica Sand Depth Interval(ft.):51-64
Conc. Pad Size: 4'x4'x6"



Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-63A

DRILLING AND SAMPLING INFORMATION

Boring Location: EAST SIDE OF FIRE TRAINING AREA 2
Logged By: M. WILSON
Drilled By: D. MEYER
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS AND MUD ROTARY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5' CONTINUOUS SAMPLER AND 1-1/2"x2' SPLIT SPOON
Notes: N 150389.964, E 2182043.019

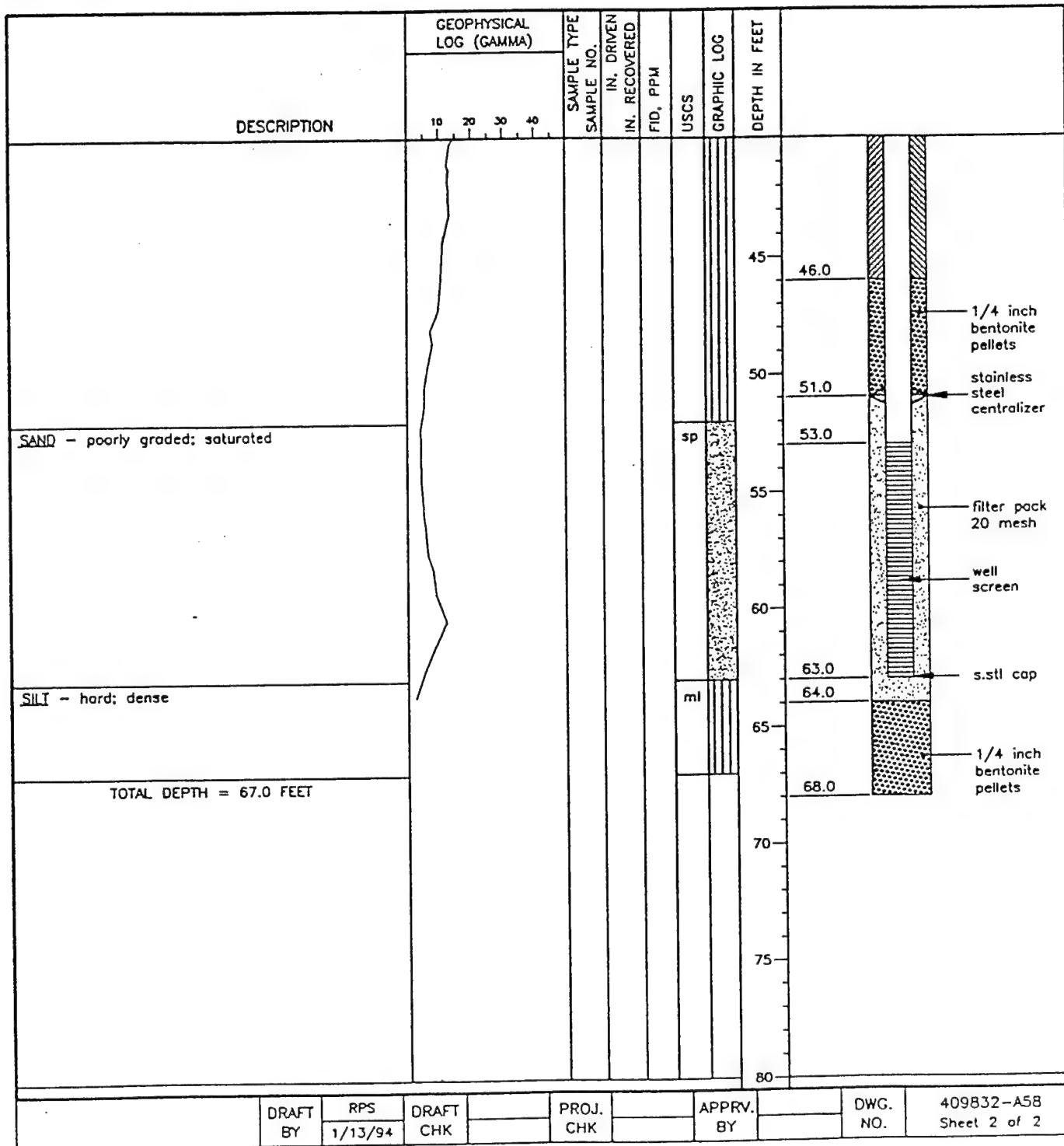
SURFACE ELEV.(FT): 1243.387
TOTAL DEPTH(FT.): 67
Date Started: 11/19/93
Date Completed: 11/23/93

GEOTECHNOLOGY, INC.

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
1. Surf Casing-I.D.(in.): 8
Centralizers-Type: S.Steel
2. Riser Pipe-I.D.(in.): 2
Centralizers-Type: S.Steel
3. Screen Dia.(in.): 2
Depth Interval(ft.): 53.0-63.0
Centralizers-Type:
4. Filter Pack Type: Silica Sand
Conc. Pad Size: 4'x4'x6"

Ref. Datum: MSL
Depth(ft.): 28 Type: Carbon Steel
Depths(ft.): 15
Depth(ft.): 53 Type: S.Steel
Depths(ft.): 21, 51
Type: S.Steel Wire Wound
Slot Size(in.): .010
Depths(ft.):
Depth Interval(ft.): 51-64



Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-64A

DRILLING AND SAMPLING INFORMATION

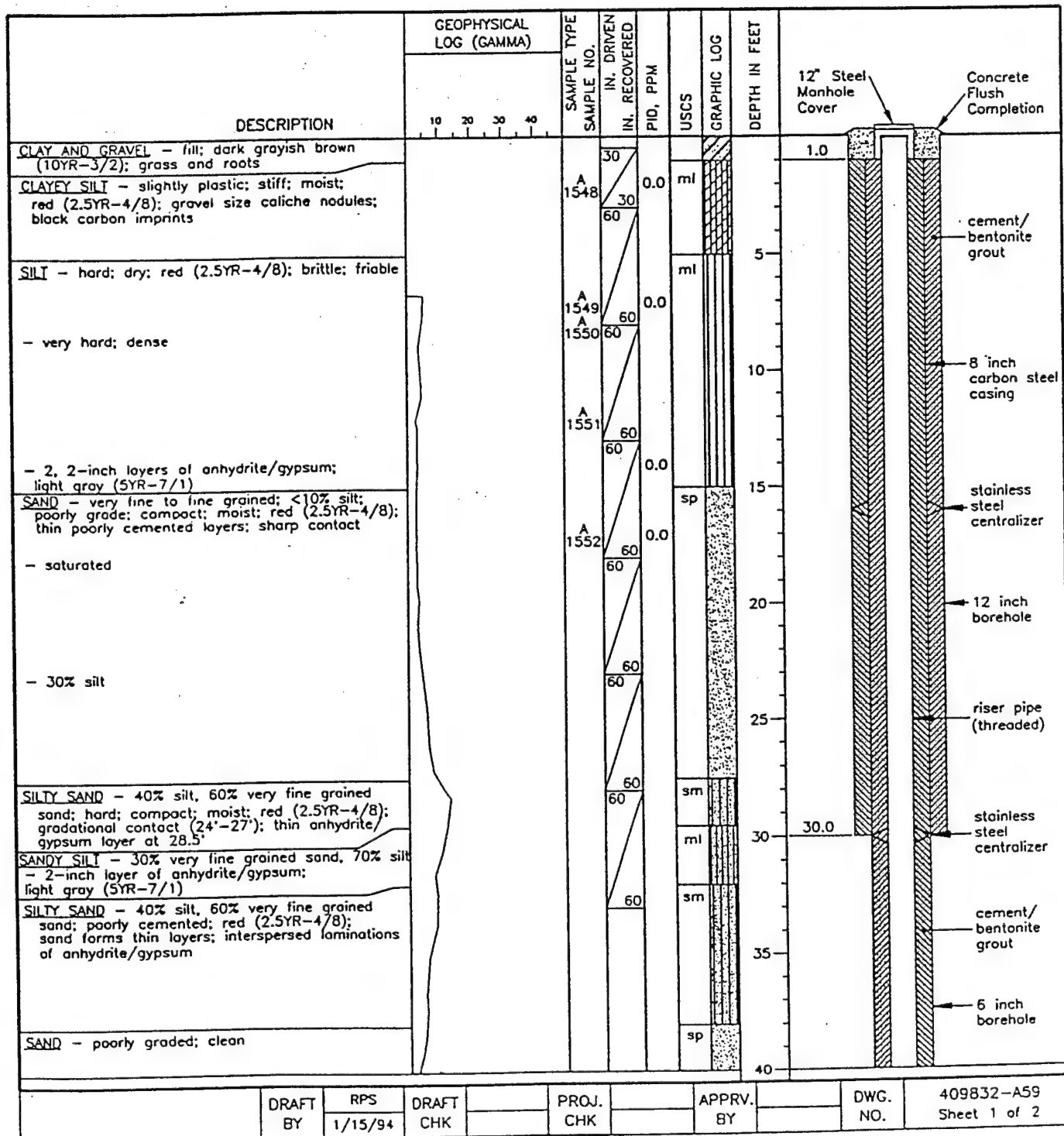
Boring Location: NORTH SIDE OF FIRE TRAINING AREA 2
Logged By: M. WILSON
Drilled By: D. MEYER
GEOTECHNOLOGY, INC.
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS AND MUD ROTARY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5" CONTINUOUS SAMPLER

Notes: N 150470.205, E 2181959.365

WELL COMPLETION DATA

Elev.-Top of Casing(ft.):
1. Surf Casing-I.D.(in.):8
Centralizers-Type: S.Steel
2. Riser Pipe-I.D.(in.): 2
Centralizers-Type: S.Steel
3. Screen Dia.(in.): 2
Depth Interval(ft.):56-66
Centralizers-Type:
4. Filter Pack Type:Silica Sand
Conc. Pad Size: 4"x4"x6"

Ref. Datum:MSL
Depth(ft.): 30 Type: Carbon Steel
Depths(ft.): 16
Depth(ft.): 56 Type: S.Steel
Depths(ft.): 30, 54
Type: S.Steel Wire Wound
Slot Size(in.): .010
Depths(ft.):
Depth Interval(ft.):54.5-67.0



Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-64A

DRILLING AND SAMPLING INFORMATION

Boring Location: NORTH SIDE OF FIRE TRAINING AREA 2
Logged By: M. WILSON
Drilled By: D. MEYER
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS AND MUD ROTARY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5' CONTINUOUS SAMPLER

SURFACE ELEV.(FT): 1246.052
TOTAL DEPTH(FT.): 75
Date Started: 11/18/93
Date Completed: 11/22/93

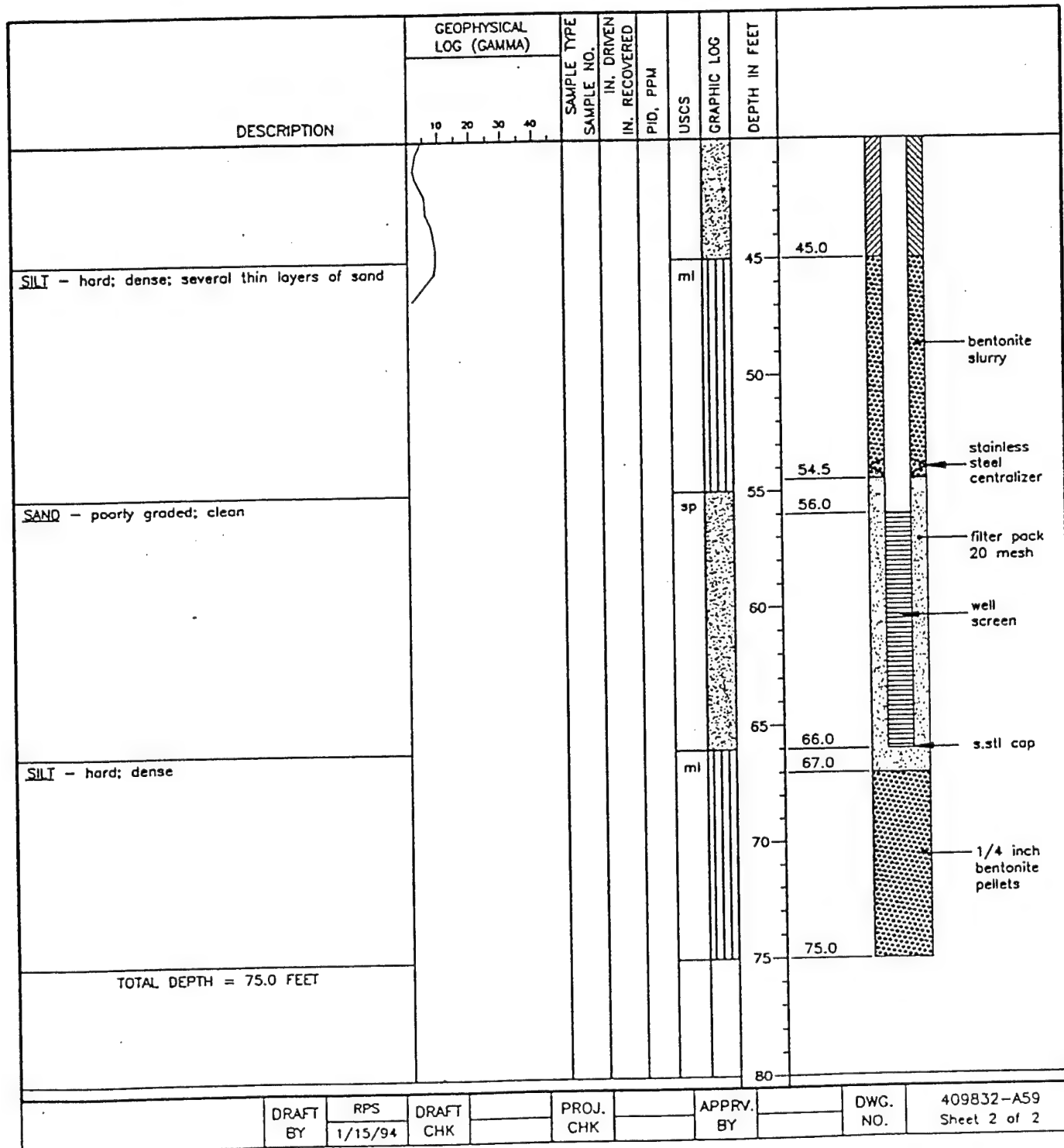
GEOTECHNOLOGY, INC.

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
1. Surf Casing-I.D.(in.): 8
Centralizers-Type: S.Steel
2. Riser Pipe-I.D.(in.): 2
Centralizers-Type: S.Steel
3. Screen Dia.(in.): 2
Depth Interval(ft.): 56-66
Centralizers-Type:
4. Filter Pack Type: Silica Sand
Conc. Pad Size: 4'x4'x6"

Ref. Datum: MSL
Depth(ft.): 30 Type: Carbon Steel
Depths(ft.): 16
Depth(ft.): 56 Type: S.Steel
Depths(ft.): 30, 54
Type: S.Steel Wire Wound
Slot Size(in.): .010
Depths(ft.):
Depth Interval(ft.): 54.5-67.0

Notes: N 150470.205, E 2181959.365



Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-65A

DRILLING AND SAMPLING INFORMATION

Boring Location: NORTHEAST OF FIRE TRAINING AREA 2
Logged By: M. WILSON
Drilled By: D. MEYER
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS

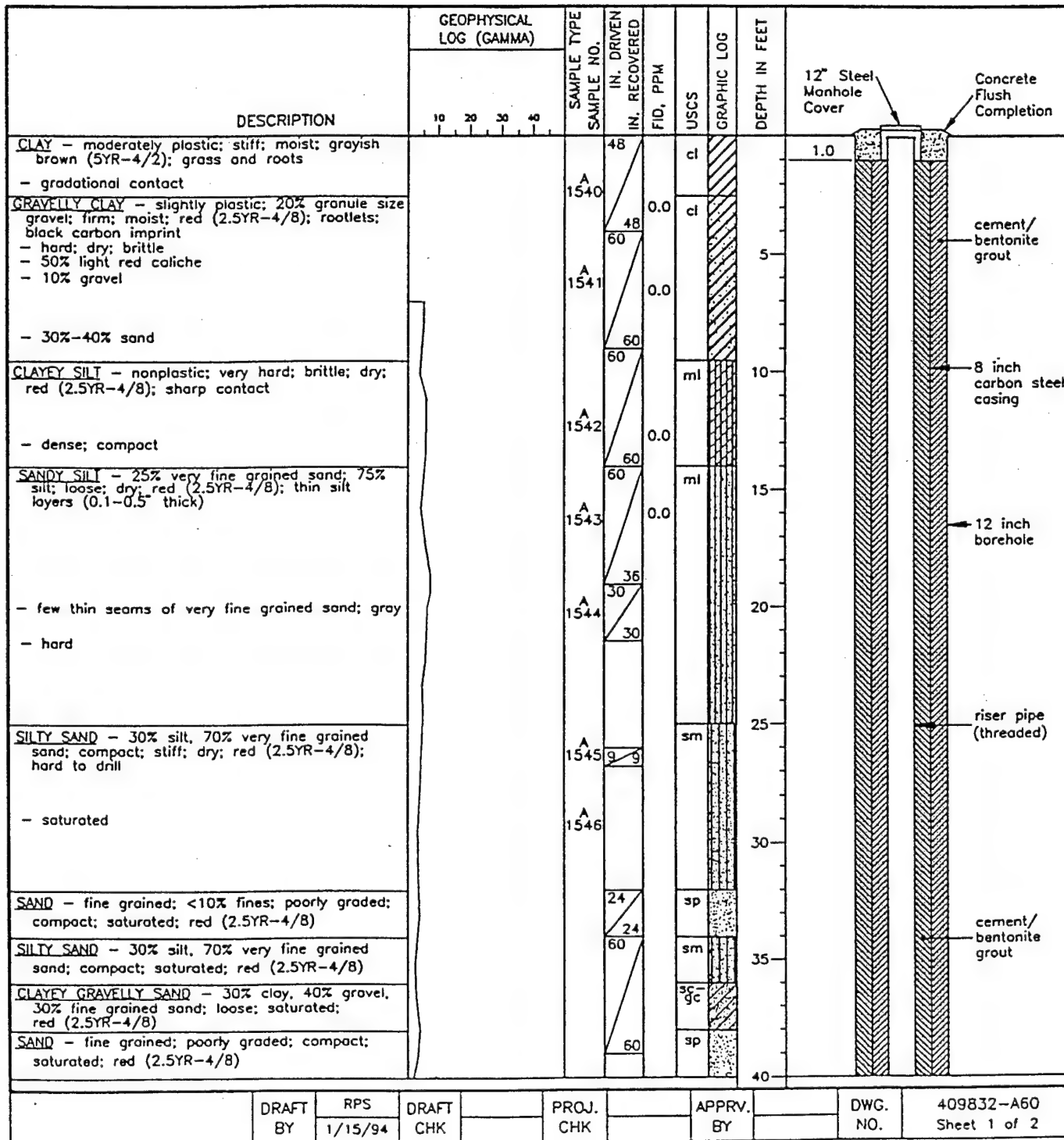
SURFACE ELEV.(FT.): 1250.976
TOTAL DEPTH(FT.): 79
Date Started: 11/15/93
Date Completed: 11/19/93
GEOTECHNOLOGY, INC.

Sampling Method: 3"x5' CONTINUOUS SAMPLER
AND 1-1/2"x2' SPLIT SPOON
Notes: N 150698.281, E 2182189.884

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
1. Surf Casing-I.D.(in.): 8
Centralizers-Type:
2. Riser Pipe-I.D.(in.): 2
Centralizers-Type: S.Steel
3. Screen Dia.(in.): 2
Depth Interval(ft.): 66-76
Centralizers-Type:
4. Filter Pack Type: Silica Sand
Conc. Pod Size: 4"x4"x6"

Ref. Datum: MSL
Depth(ft.): 55 Type: Carbon Steel
Depths(ft.):
Depth(ft.): 66 Type: S.Steel
Depths(ft.): 61
Type: S.Steel Wire Wound
Slot Size(in.): .010
Depths(ft.):
Depth Interval(ft.): 64-77



DRAFT
BY

RPS
1/15/94

DRAFT
CHK

PROJ.
CHK

APPRV.
BY

DWG.
NO.

409832-A60
Sheet 1 of 2

Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-65A

DRILLING AND SAMPLING INFORMATION

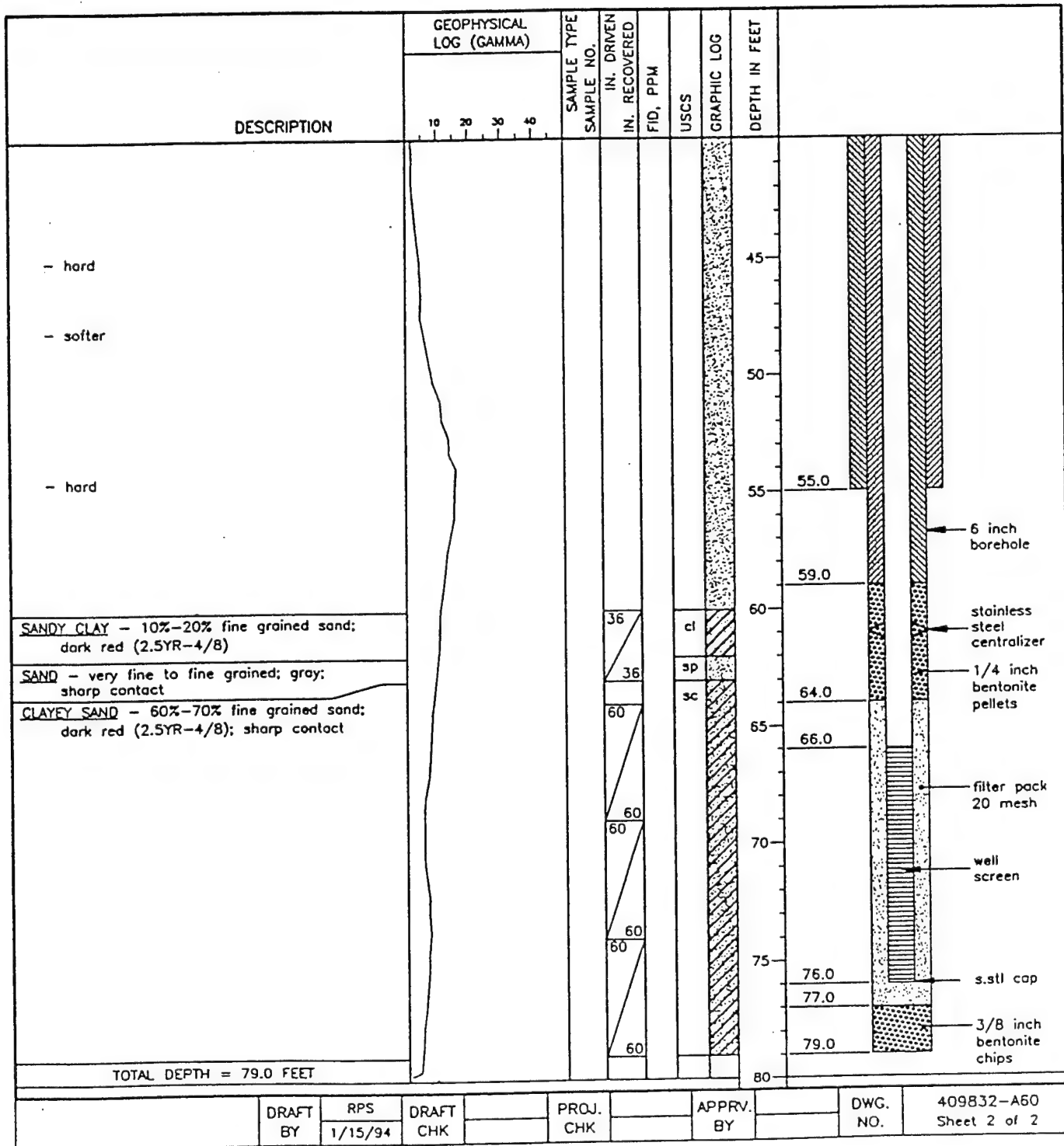
Boring Location: NORTHEAST OF FIRE TRAINING AREA 2
Logged By: M. WILSON
Drilled By: D. MEYER
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS
Sampling Method: 3"x5' CONTINUOUS SAMPLER AND 1-1/2"x2' SPLIT SPOON
Notes: N 150698.281, E 2182189.884

SURFACE ELEV.(FT.): 1250.976
TOTAL DEPTH(FT.): 79
Date Started: 11/15/93
Date Completed: 11/19/93
GEOTECHNOLOGY, INC.

WELL COMPLETION DATA

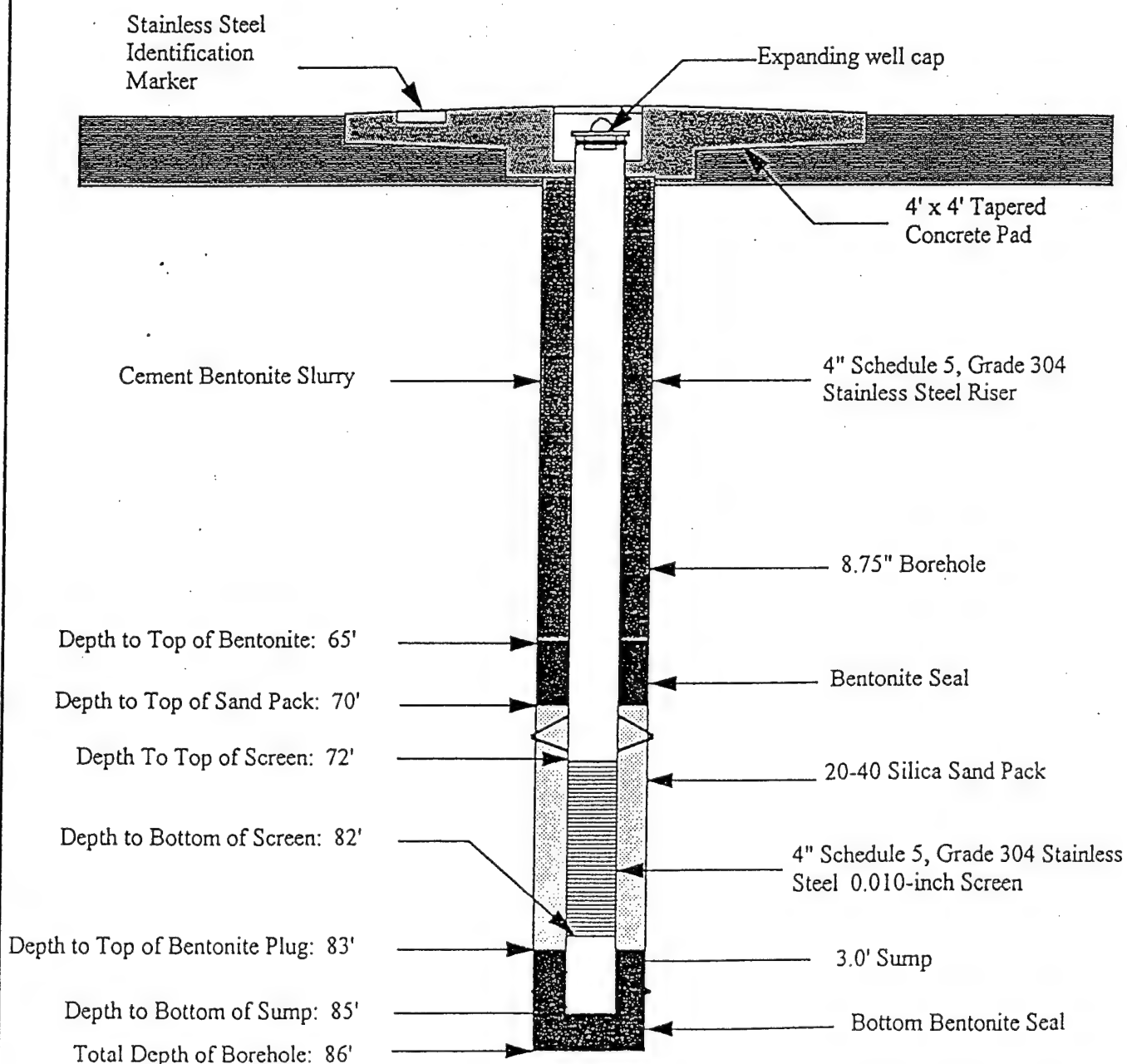
Elev-Top of Casing(ft.):
1. Surf Casing-I.D.(in.): 8
Centralizers-Type:
2. Riser Pipe-I.D.(in.): 2
Centralizers-Type: S.Steel
3. Screen Dia.(in.): 2
Depth Interval(ft.): 66-76
Centralizers-Type:
4. Filter Pack Type: Silica Sand
Conc. Pad Size: 4'x4'x6'

Ref. Datum: MSL
Depth(ft.): 55 Type: Carbon Steel
Depths(ft.):
Depth(ft.): 66 Type: S.Steel
Depths(ft.): 61
Type: S.Steel Wire Wound
Slot Size(in.): .010
Depths(ft.):
Depth Interval(ft.): 64-77



WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-142A
Location: TAFB, Oklahoma	Site: BW
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/19/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1242.30'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1241.76'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	

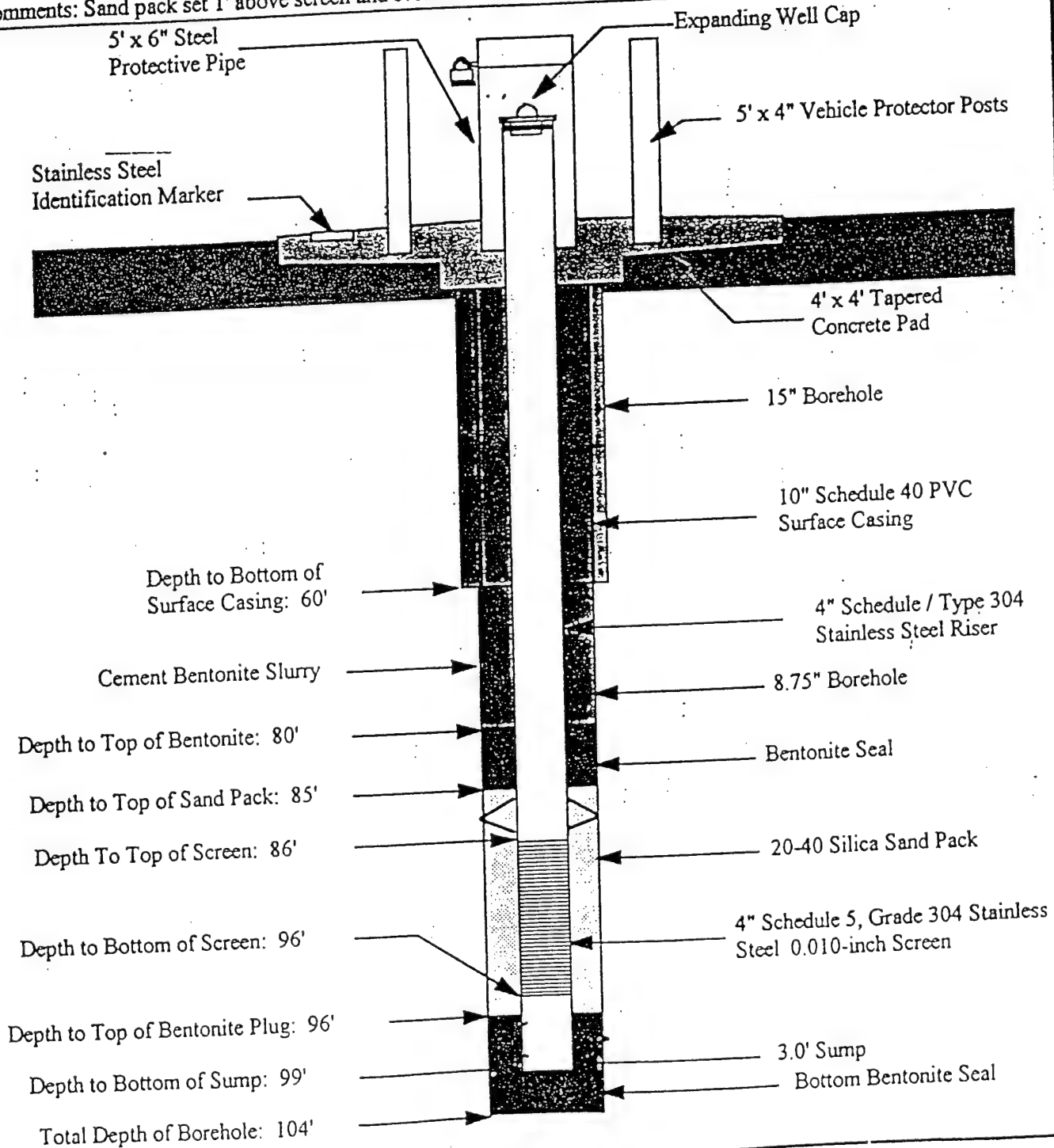


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-112A
Location: TAFB, Oklahoma	Site: LF15
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 1/23/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1248.03'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1251.41'
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Sand pack set 1' above screen and even with screen bottom. Top Riser: 4" Schedule 40 PVC Casing.	



< > Centralizers

Drawing not to scale

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

SOIL BORING 2-65P

DRILLING AND SAMPLING INFORMATION

Boring Location:	NORTH OF FIRE TRAINING AREA	SURFACE ELEV.(FT.):	
Logged By:	K. KIRSCHENMANN	TOTAL DEPTH(FT.):	100.0
Drilled By:	P. GUERREIN	Date Started:	11/2/93
		Date Completed:	11/3/93

GEOTECHNOLOGY, INC.

Drill Rig Type: CME-75

Drilling Method: 8" HOLLOW STEM AUGER AND

MUD ROTARY WITH 3-7/8" BIT

Sampling Method:

Notes: STRATIGRAPHIC TEST USED FOR GEOPHYSICAL LOGGING

DESCRIPTION				GEOPHYSICAL LOG (GAMMA)				SAMPLE TYPE SAMPLE NO.	IN. DRIVEN IN. RECOVERED	PID, PPM	USCS	GRAPHIC LOG	DEPTH IN FEET	
				10	20	30	40							
<u>SILTY CLAY</u> - very hard										0		cl		85
														90
TOTAL DEPTH = 100.0 FEET													95	
													100	
													105	
													110	
													115	
													120	

DRAFT BY	RPS 11/24/93	DRAFT CHK	PROJ. CHK	APPRV. BY	DWG. NO.	409832-A27 Sheet 3 of 3
----------	-----------------	-----------	-----------	-----------	----------	----------------------------

Analytical Results for Fire Training Area 2
For USZ Groundwater
↓ Tinker Air Force Base, Oklahoma

Table 5-3

Parameters	12/10/93		12/10/93		12/10/93		12/10/93		12/10/93	
	2-62B A1601	2-62B A1602	2-62B A1665	2-63B A1600	2-64B A1603	2-65B A1604	Result	QFR	Result	QFR
Well/Boring: Sample ID: Depth in Feet:	0-0	0-0	0-0	0-0	0-0	0-0				
Metals (mg/L)	Result	Result	Result	Result	Result	Result				
Aluminum	8.2	5.1		5.9	1.4	0.95				
Barium	0.21	0.19		0.35	0.23	0.24				
Calcium	48 N	58 N		61 N	59 N	80 N				
Chromium	0.04 N	0.029 N		0.014 N						
Copper	0.043 N	0.049 N								
Iron	11	5.5		13	.2	1.1				
Lead - Graphite Furnace	0.004	0.0031								
Magnesium	43	52		45	33	52				
Manganese	0.14 N	0.1 N		0.23 N	0.048 N	0.065 N				
Potassium						1.7				
Selenium				0.1 N						
Sodium	110	130		59	46	43				
Zinc	0.024 N	0.021 N		0.022 N						
Semivolatiles (ug/L)										
1,3-Dichlorobenzene	53	46								
Volatiles (ug/L)										
1,1,2-Trichloroethane	9	7.3								
1,1-Dichloroethene	5.7	6								
1,2-Dichlorobenzene	1900 D	1700 D								
1,2-Dichloroethane	500	550								
1,2-Dichloropropane	7	7.3								
1,4-Dichlorobenzene	290 D	250 D								
Benzene	5.4	5.7								
Chlorobenzene	220	240								
Trichloroethene	8300 D	8900 D								
cis-1,2-Dichloroethene	1600 D	1700 D								
trans-1,2-Dichloroethene	130	140								

Analytical Results for Fire Training Area 2
For USZ Groundwater
Tinker Air Force Base, Oklahoma
Table 5-3

Parameters	Miscellaneous (mg/L)															
	2-62B A1601 0-0	Result	QFR	2-62B A1602 0-0	Result	QFR	2-62B A1665 0-0	Result	QFR	2-63B A1600 0-0	Result	QFR	2-64B A1603 0-0	Result	QFR	2-65B A1604 0-0
Well/Boring: Sample ID: Depth in Feet:																
Alkalinity, Titrimetric	520			330						470			380			500
Chemical Oxygen Demand	35															
Chloride by Ion Chrom.	87			89						39			34			57
Nitrate and Nitrite	2.9			2.7						3.8			3.8			2.6
Silica	7.3			6.9						8.9			4.3			11
Sulfate by Ion Chrom.	110			230						36			24			37
Total Phosphorus	0.15															
Total Dissolved Solids	630			660						510			450			650
Total Kjeldahl Nitrogen	0.38															
Total Organic Carbon	3			3						2.2			1.2			1.6
Total Suspended Solids	190			250						750			160			42
B = Analyte was also found in sample blank																
D = Compound identified at a secondary dilution factor.																
E = Concentration exceeds instrument calibration range for that specific analysis																
J = Concentration is an estimated value																
N = Sample is outside of Matrix Spike QC Limit																
< = Not detected																
QFR = Qualifier																
Analytical data has not been validated																

Analytical Results for Fire Training Area 2
For LSZ Groundwater
Tinker Air Force Base, Oklahoma

Table 5-4

Parameters	2-62A		2-63A		2-64A		2-65A	
	A1648	QFR	A1607	QFR	A1608	QFR	A1609	QFR
Well/Boring: Sample ID: Depth in Feet:	0-0		0-0		0-0		0-0	
Result			Result		Result		Result	
Metals (mg/L)								
Aluminum	1.5		32 N		2.9 N		2.8 N	
Arsenic - Graphite Furnace			0.018					
Barium	0.56		3.7		0.56			
Cadmium			0.0066					
Calcium	68		100		61		36	
Chromium	0.021		0.12 N		0.075 N		0.053 N	
Copper			0.1					
Iron	1.1		57		4.8		4.3	
Lead - Graphite Furnace			0.025		0.0042			
Magnesium	42		57		35		19	
Manganese	0.016		1.2 N		0.12 N		0.067 N	
Nickel			0.079 N		0.067 N			
Potassium			7.3					
Sodium	45		25		23		22	
Zinc			0.1 N		0.021 N		0.028 N	
Miscellaneous (mg/L)								
Total Dissolved Solids	450		190		388		258	
Total Kjeldahl Nitrogen							0.26 N	
Total Suspended Solids	45		1900		200		190	
Alkalinity, Titrimetric	390		380		350		24	
Chloride by Ion Chrom.	9.9		17		26		0.78	
Nitrate and Nitrite	5.3		3.3		1.1		11	
Silica	11		8.8		8.6		24 N	
Sulfate by Ion Chrom.	17		17 N		14 N		3.9 N	
Total Phosphorus			0.19 N					
B = Analyte was also found in sample blank								
E = Concentration exceeds instrument calibration range for that specific analysis								
J = Concentration is an estimated value								
N = Sample is outside of Matrix Spike QC Limit								
< = Not detected								
QFR = Qualifier								
Analytical data has not been validated								

B = Analyte was also found in sample blank

E = Concentration exceeds instrument calibration range for that specific analysis

J = Concentration is an estimated value

N = Sample is outside of Matrix Spike QC Limit

< = Not detected

QFR = Qualifier

Analytical data has not been validated

DRAWING
NUMBER

APPRV.
BY

PROJ.
CHK

DRAFT
CHK

DRAFT
BY

NW-SE RUNWAY

FIRE TRAINING AREA 2

FIRE TRAINING AREA 3

2-65B
99

2-62B
8900

2-64B
96

2-63B
33

935

CONTROL
TOWER

1076

Map Source: TINKER AFB

LEGEND

2-63B
33

SHALLOW MONITORING WELL LOCATION,
IDENTIFICATION NUMBER, AND
TRICHLOROETHENE CONCENTRATION
IN $\mu\text{g/L}$

—X—X— FENCE

— DRAINAGE

— 100 — LINE OF EQUAL TRICHLOROETHENE
CONCENTRATION IN $\mu\text{g/L}$ (DASHED
WHERE INFERRED)

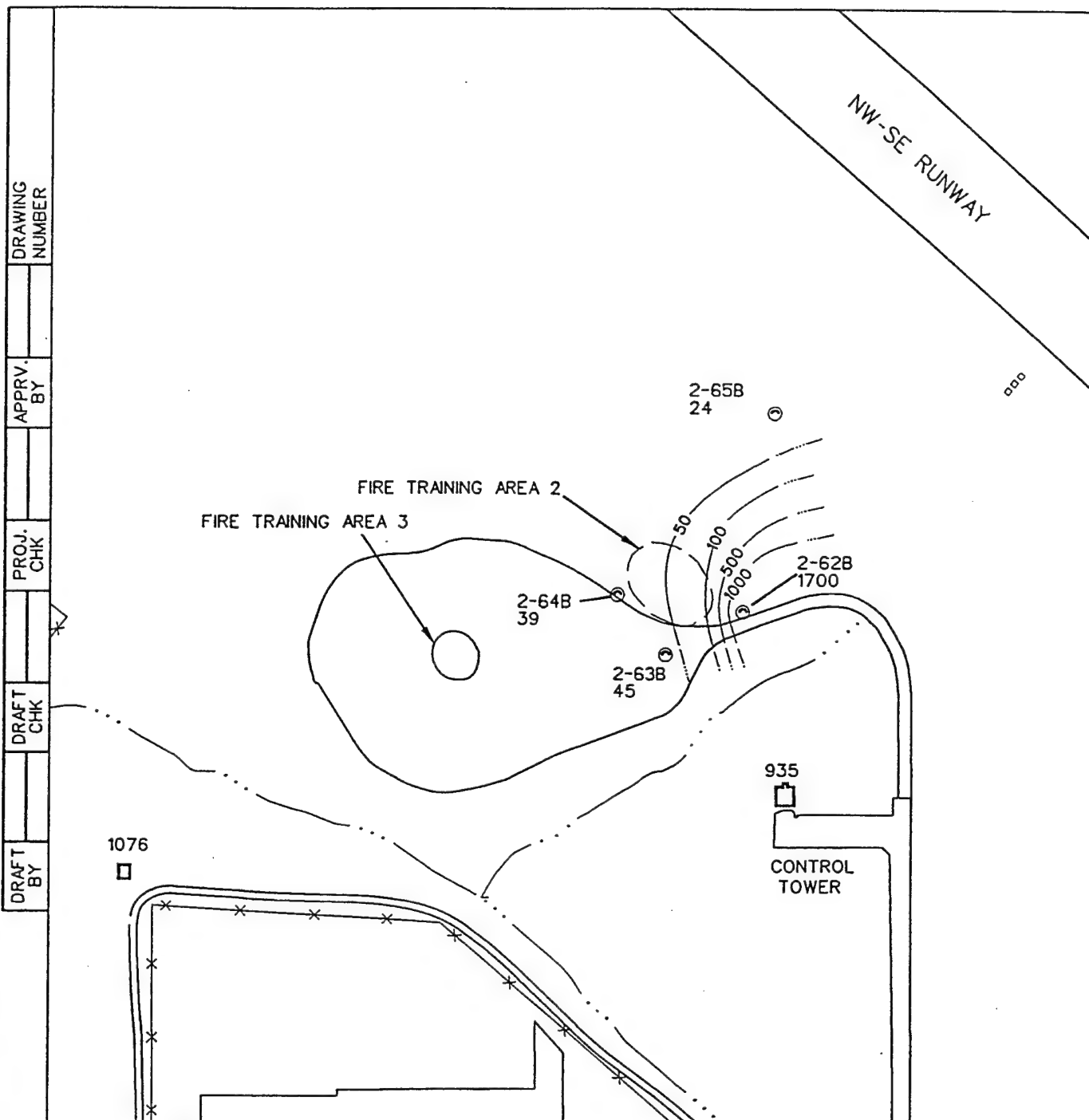


0 200
FEET

FIGURE 5-5
ISOPLETH MAP OF
TRICHLOROETHENE CONCENTRATION
OF THE UPPER SATURATED ZONE
AT FIRE TRAINING AREA 2

PREPARED FOR
TINKER AFB
OKLAHOMA

G:\TINKER\40983202.135
Do Not Scale This Drawing



Map Source: TINKER AFB

LEGEND

● 2-63B 45 SHALLOW MONITORING WELL LOCATION, IDENTIFICATION NUMBER, AND 1,2 DICHLOROETHANE CONCENTRATION IN $\mu\text{g/L}$

—X—X— FENCE

— DRAINAGE

— 50 — LINE OF EQUAL 1,2 DICHLOROETHANE CONCENTRATION IN $\mu\text{g/L}$ (DASHED WHERE INFERRED)



0 200
FEET

FIGURE 5-6
ISOPLETH MAP OF
CIS 1,2 DICHLOROETHANE CONCENTRATION
OF THE UPPER SATURATED ZONE
AT FIRE TRAINING AREA 2

PREPARED FOR
TINKER AFB
OKLAHOMA

G:\TINKER\40983202.136

Do Not Scale This Drawing

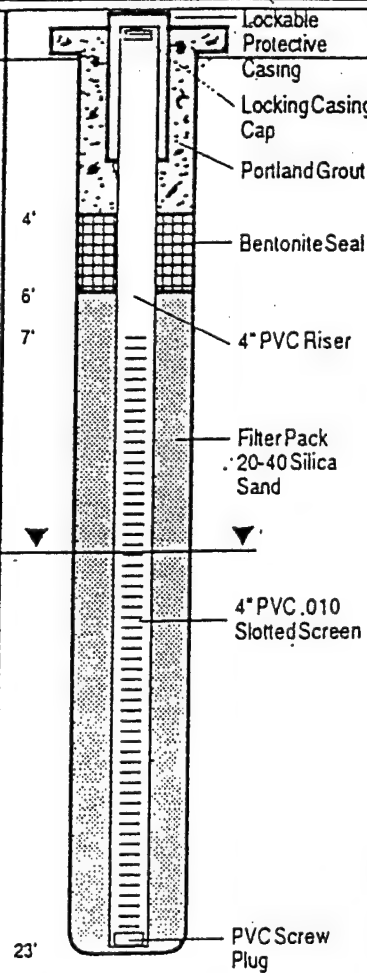
APPENDIX C

**ADDITIONAL SITE DATA
AREA A**

BORING LOG

(CP)

Depth (feet)	Lithology Description	Graphic Log	USCS Class.	Well Construction	Remarks
0					PID READING
.67	Topsoil; clay				
2.3	Fill material; red brown clay				1.5' 0 ppm
5	Clay; plastic; brown				4.1' 0 ppm
5.9	Clay; plastic; brown red				6.5' 0 ppm
10					7.5' 4 ppm
10.2	Clay; gray				9.2' 512 ppm
10.4	Silt; clayey; soft; red brown				10.3' 25 ppm
12	Silt; some fine sand; clayey; red brown; thinly laminated				11' 406 ppm
15					12' 3 ppm
17	Siltstone; red brown; thinly laminated				14' 48 ppm
17.5	Clay; plastic; firm; red brown				15' 12 ppm
19	Sandstone; fine-medium grained; red brown; water saturated				17' 14 ppm
20	Siltstone; red brown; thinly laminated				17.5' 4 ppm
21.5	Sand; fine grained; red brown; wet; auger refusal at 23'				19.5' 5 ppm
23					21' 0 ppm
25	T.D. 23'				21.75' 1 ppm
30					22.5' 0 ppm

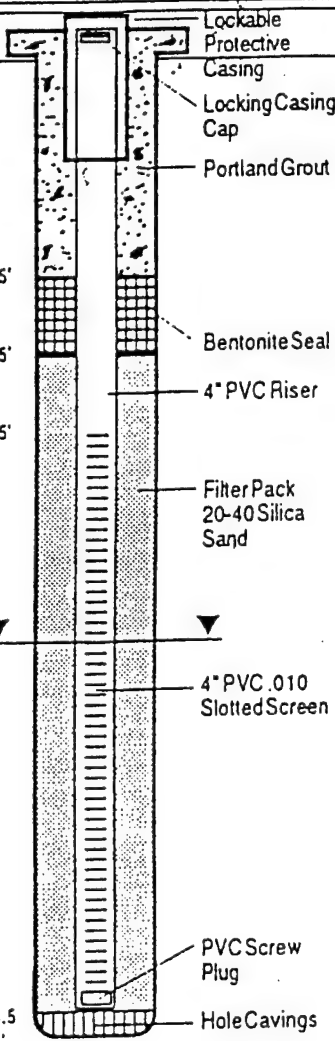


MONITOR WELL #2-2
Static Water Level - 12.69'

Project Number: 90-164	Client: USAF - POL SITE "A"	Driller: A. W. Pool, Inc.
Boring Number: SB-7	Date Drilled: 20 May 1991	Drill Type: Hollow Stem Auger
Logged By: DLW	Elevation: 1242.34 Feet	

BORING LOG

Depth (feet)	Lithology Description	Graphic Log	USCS Class.	Well Construction	Remarks
0					PID READING
2	No samples				
5	Clay; slightly silty; plastic; mottled dark brown to red				3' 0 ppm
6	Clay; plastic; brown red				6' 0 ppm
7	Clay; plastic; red; thin bedded and alternating with thin bedded, red brown clayey silt				7' 582 ppm
10					8' 315 ppm
12	Silt; very clayey; brown red				9' 11 ppm
14	Clay; silty; brown red				10' 9 ppm
15					13' 577 ppm
17	Siltstone; gray green				14' 157 ppm
20	Sand; fine grained; silty; brown red; massive bedded in upper 2', thin bedded below; top water saturation occurs at 19' - 20'				15' 15 ppm
24					16' 452 ppm
25	Sand; fine grained; light gray				17' 217 ppm
					18' 17 ppm
					20' 5 ppm
					23' 16 ppm
					25' 0 ppm
	T.D. 25'				
30					



MONITOR WELL #2-3

Static Water Level - 14.86'

Project Number: 90-164

Client: USAF - POL SITE "A"

Driller: A. W. Pool, Inc.

Boring Number: SB-8

Date Drilled: 23 May 1991

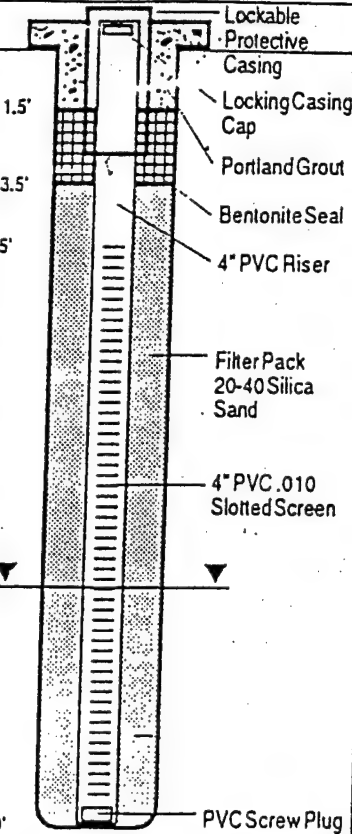
Drill Type: Hollow Stem Auger

Logged By: JLT

Elevation: 1242.60 Feet

BORING LOG

Depth (feet)	Lithology Description	Graphic Log	USCS Class.	Well Construction	Remarks
0					PID READING
2	Fill material			1.5' Lockable Protective Casing	
5	Clay; silty; mottled gray; soft			3.5' Locking Casing Cap	3' 0 ppm
7				5' Portland Grout	5' 32 ppm
9.5				Bentonite Seal	7' 4 ppm
10	Silt; very clayey; red brown; crumbly			4" PVC Riser	8' 3 ppm
12				Filter Pack 20-40 Silica Sand	10' 362 ppm
15	Silt to fine sand; red brown; loosely to well cemented			4" PVC .010 Slotted Screen	12' 745 ppm
16	Silt to fine sand; red brown; alternating thin zones of loosely and well cemented material				14' 437 ppm
20	Sandstone; fine grained; red brown; thinly laminated; water saturated at top				15' 563 ppm
	Auger refusal at 16' - drilled without core barrel to 20'				16' 566 ppm
25	T.D. 20'				
30	Note: Water level in boring at 14.5' after 20 minutes with thin floating layer of free product.				



MONITOR WELL #2-4
 Top Fuel - 12.67'
 Top Water - 17.12'
 Effective Static Water Level - 13.83'

Project Number: 90-164	Client: USAF - POL SITE "A"	Driller: A. W. Pool, Inc.
Boring Number: SB-4	Date Drilled: 20 May 1991	Drill Type: Hollow Stem Auger
Logged By: DLW	Elevation: 1243.22 Feet	

Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-5C

DRILLING AND SAMPLING INFORMATION

Boring Location: EAST OF
CIVIL ENGINEERING BLDG
Logged By: V. CRNICH
Drilled By: B. HYBER
NESCO
Drill Rig Type: B-61 HD
Drilling Method: 8-1/4" HOLLOW STEM AUGER

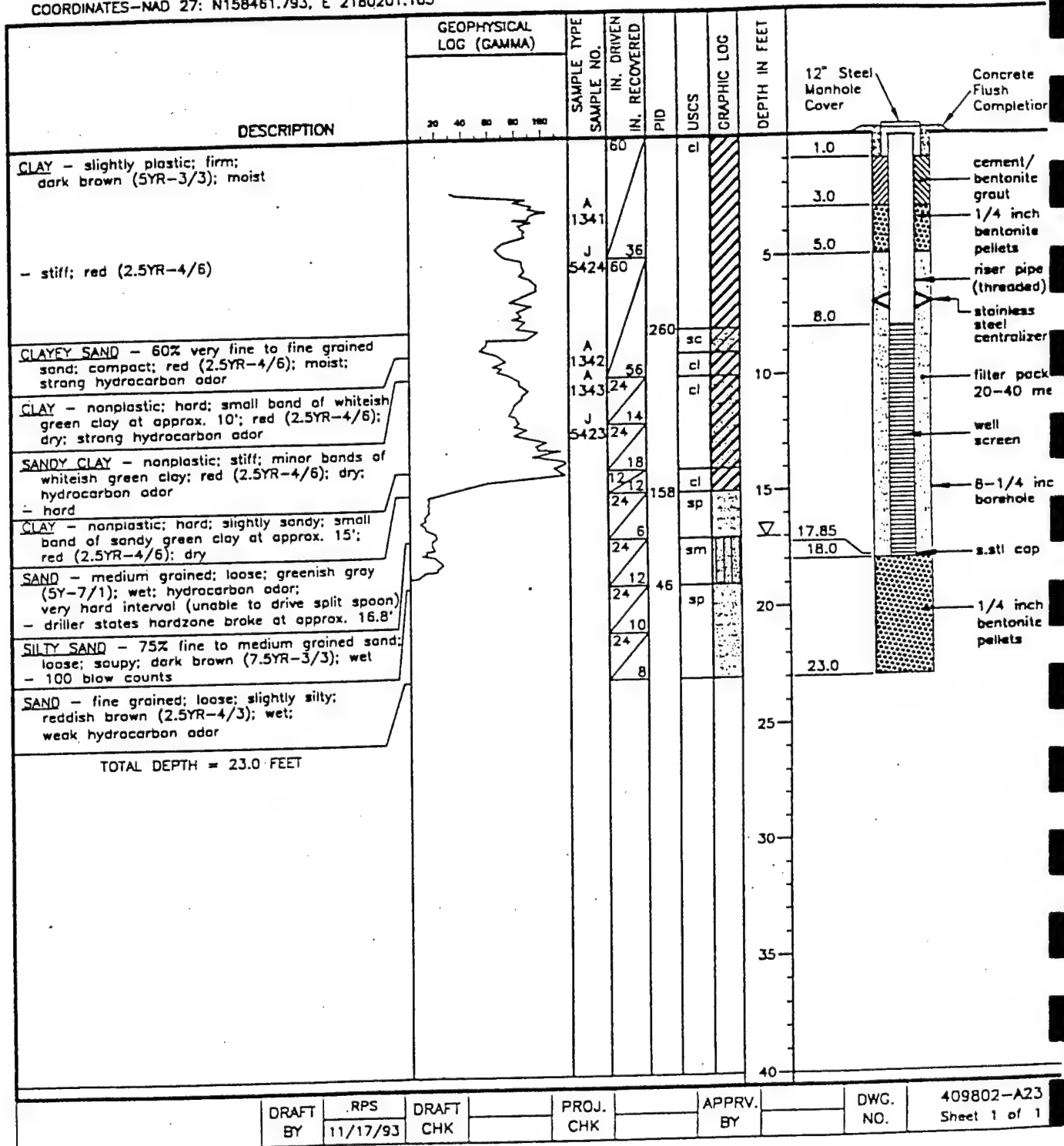
PAD ELEV.(FT): 1241.38
TOTAL DEPTH(FT.): 23
Date Started: 10/25/93
Date Completed: 10/26/93

Sampling Method: 5'x4" CONTINUOUS SAMPLER AND
2'x2" SPLIT SPOON

Notes: GEOTECH SAMPLES COLLECTED FROM THE 5-7' AND THE 12-14' INTERVALS;
SPLIT SPOON HAMMERED TO 100 BLOW COUNTS BEFORE PULLING IT OUT OF HOLE
COORDINATES-NAD 27: N158461.793, E 2180201.105

WELL COMPLETION DATA

Elev-Top of Casing(FL): 2141.30 Ref. Datum: NGVD
1. Riser Pipe-LD(in.): 2 Depth(FL): 8.0 Type: S.Steel
Centralizers-Type: S.Steel Depths(FL): 7.0
2. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(FL): 8.0-17.85 Slot Size(in.): .010
Centralizers-Type: Depths(FL):
3. Filter Pack Type: Silica Sand Depth Interval(FL): 5.0-18.0
Conc. Pad Size: 4'x4'x6"



Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-5

DRILLING AND SAMPLING INFORMATION

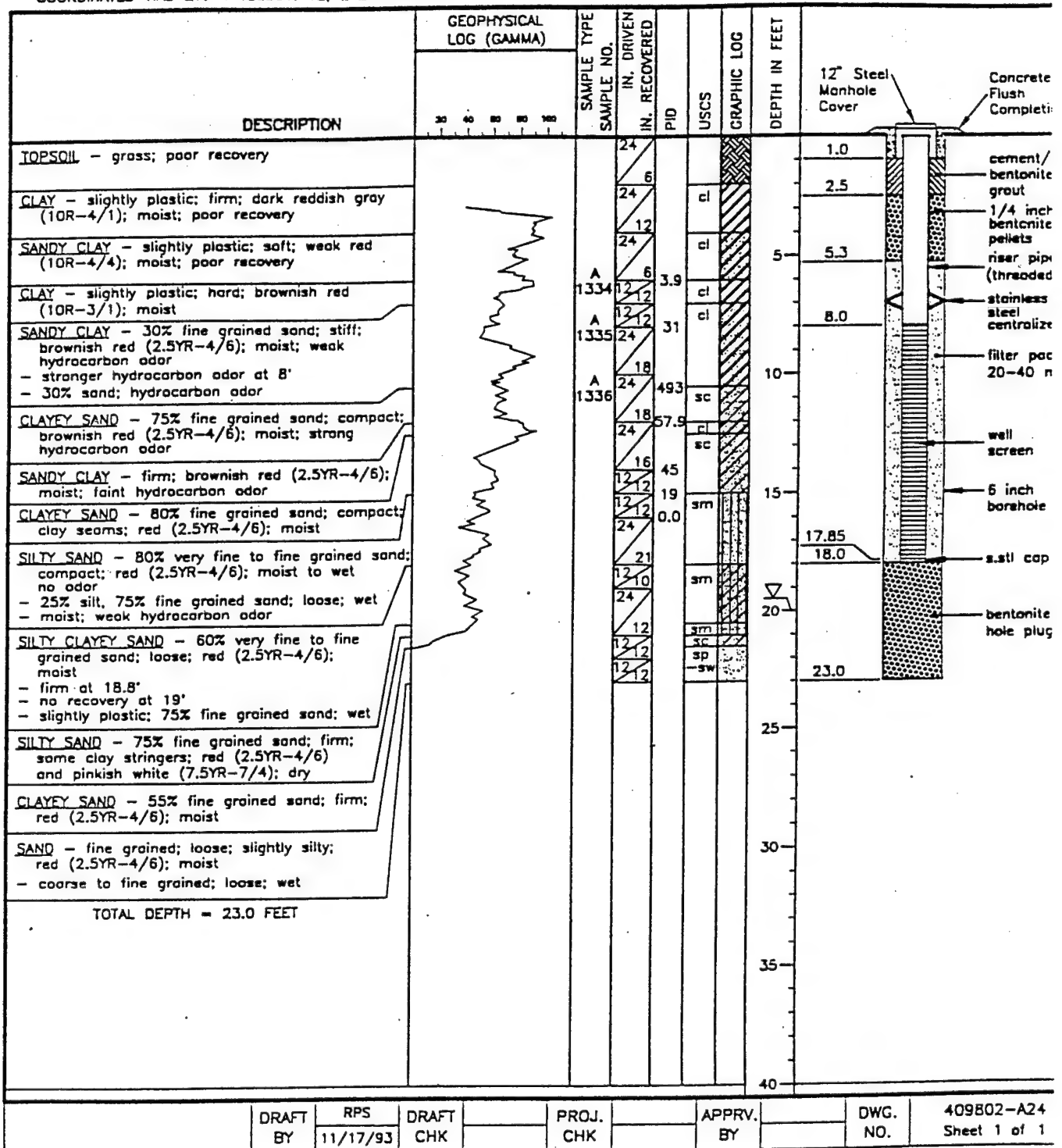
Boring Location: SOUTHEAST OF BUILDING 410
Logged By: V. CRNICH
Drilled By: T. PATTERSON
Drill Rig Type: SIMCO 2800 HS HT
Drilling Method: 6" HOLLOW STEM AUGER

Sampling Method: 2'x 2" SPLIT SPOON

Notes: CREW USING CRISCO AS LUBRICANT ON SPLIT SPOONS;
HIT WATER AT 16 FEET
COORDINATES-NAD 27: N 158301.112, E 2180427.530

WELL COMPLETION DATA

Elev-Top of Casing(ft.): 1241.29 Ref. Datum: NGVD
1. Riser Pipe-LD.(in.): 2 Depth(ft.): 8.0 Type: S.Steel
Centralizers-Type: S.Steel Depths(ft.): 7.0
2. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(ft.): 8.0-17.85 Slot Size(in.): .010
Centralizers-Type: Depths(ft.):
3. Filter Pack Type: Silica Sand Depth Interval(ft.): 5.3-18.0
Conc. Pod Size: 4'x4'x6"



Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

2-523
MONITORING WELL 2-5

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A PAD ELEV.(FT): 1239.95
TOTAL DEPTH(FT.): 23
Logged By: V. CRNICH Date Started: 10/22/93
Drilled By: T. PATTERSON Date Completed: 10/25/93
NESCO
Drill Rig Type: SIMCO 2800 HS HT
Drilling Method: 6" HOLLOW STEM AUGER

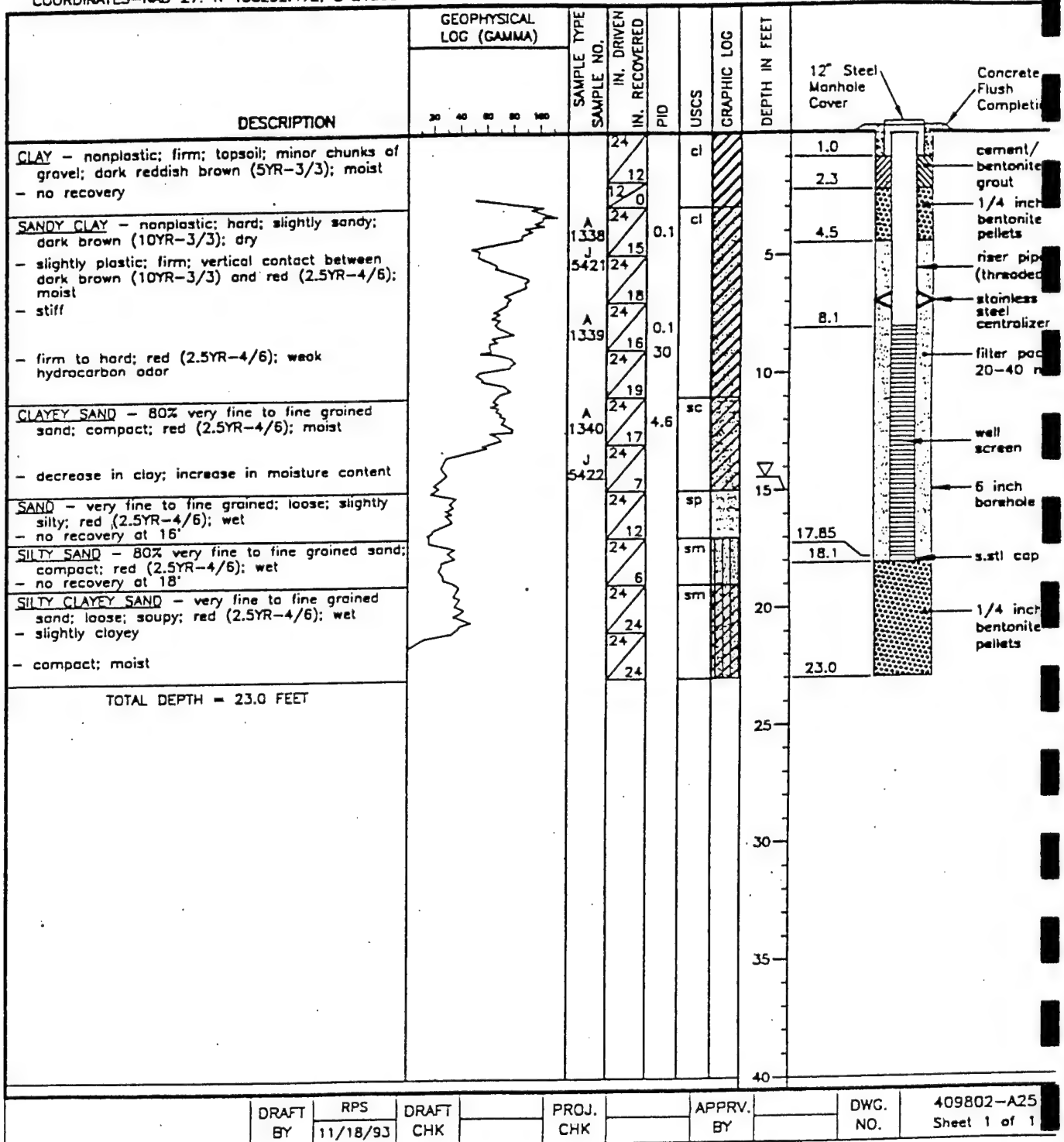
Sampling Method: 2'x 2" SPLIT SPOON

WELL COMPLETION DATA

Elev-Top of Casing(FT.): 1241.81 Ref. Datum: NGVD
1. Riser Pipe-LD.(in.): 2 Depth(FT.): 8.1 Type: S.Steel
- Centralizers-Type: S.Steel Depths(FT.): 7.0
2. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(FT.): 8.1-17.85 Slot Size(in.): .010
Centralizers-Type: Depths(FT.):
3. Filter Pack Type: Silica Sand Depth Interval(FT.): 4.5-18.1
Conc. Pad Size: 4'x4'x6"

Notes: CREW USING CRISCO AS LUBRICANT ON SPLIT SPOONS;

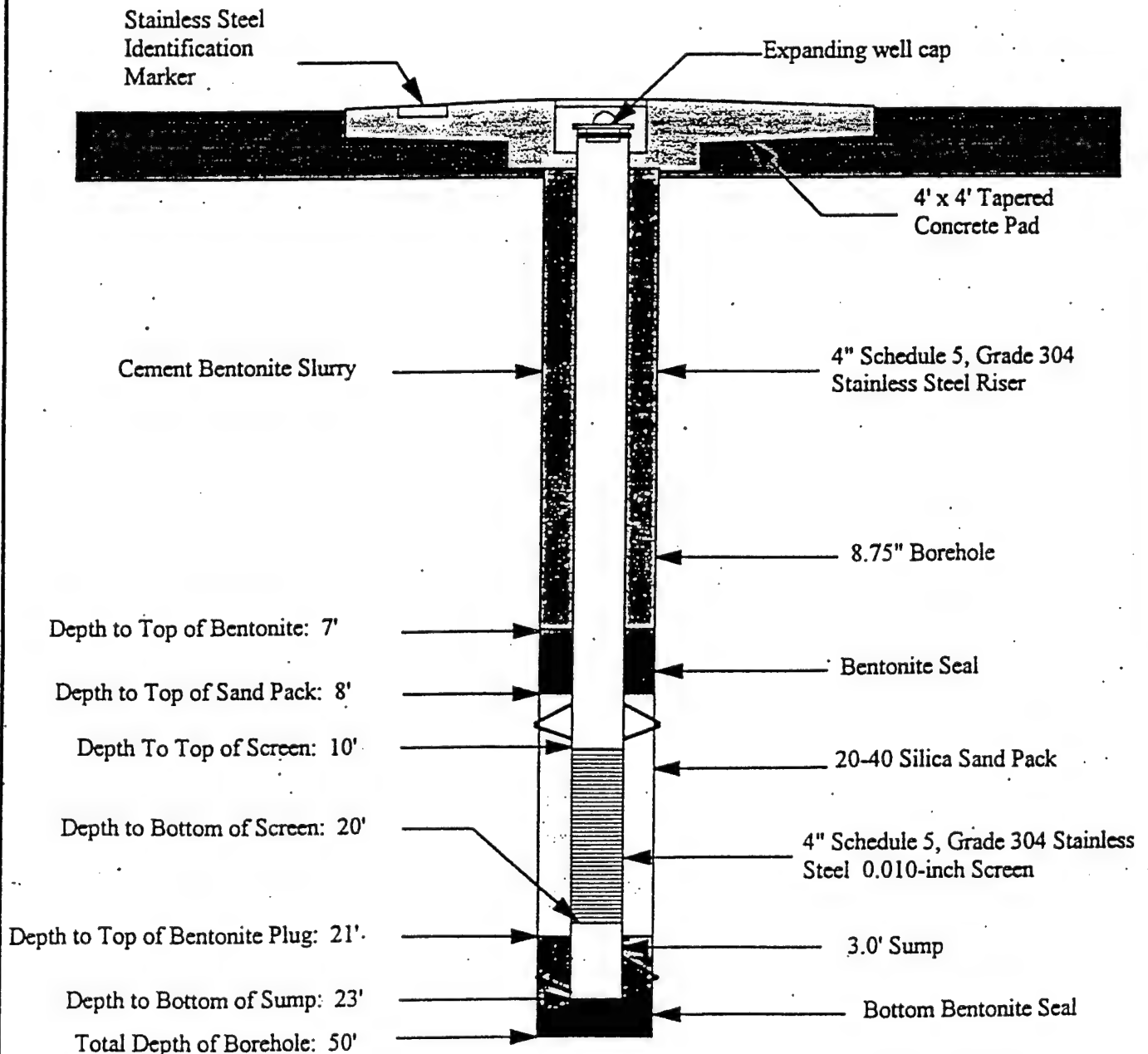
GEOTECH SAMPLES COLLECTED FROM THE 5-7' AND THE 13-15' INTERVAL
COORDINATES--NAD 27: N 158292.472, E 2180247.692



WELL CONSTRUCTION SCHEMATIC



Client: Tinker Air Force Base	Well ID: 2-163B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 06/01/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL):
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL):
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing. 1' thick top bentonite seal set.	

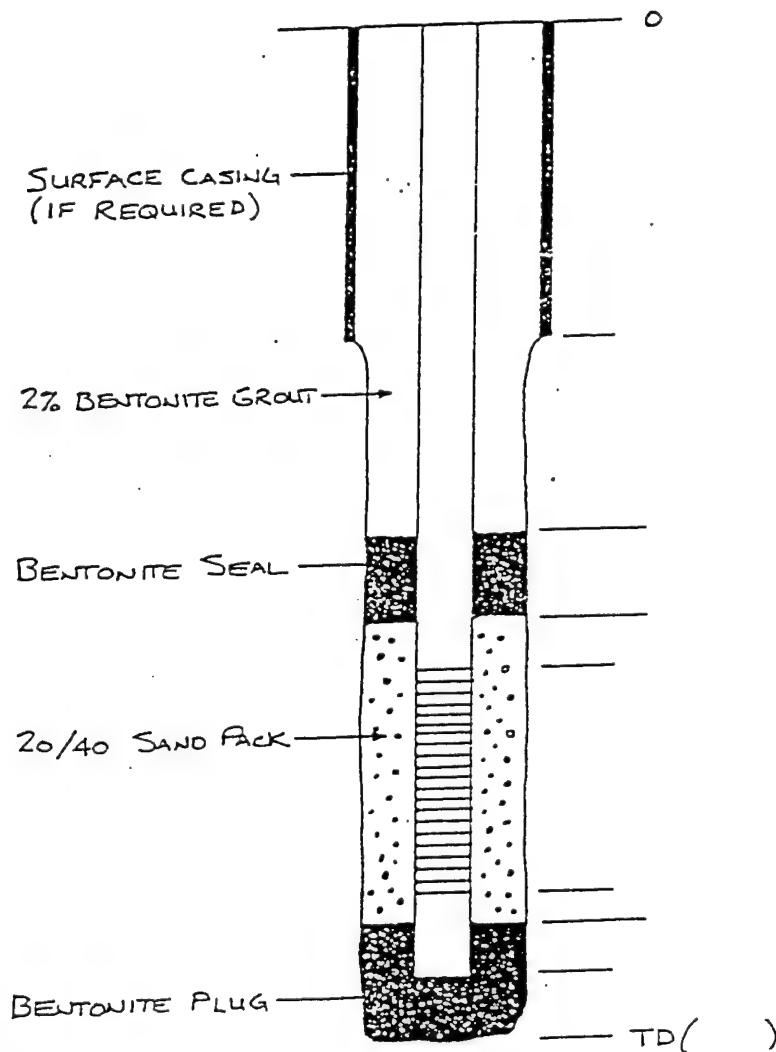


Drawing not to scale

< > Centralizers

(2)

Well ID	Recommended Construction		Comments
	Item	Depth	
2-1638	Surface Casing		
	Inner Casing		
	Grout	0-7	
	Bentonite Seal (top)	7-8	
	Sand Pack	8-21	
	Bentonite Seal (bottom)	21-TD	
	Riser	0-10	
	Screen	10-20	
	Sump	20-23	



Log Received
9:00 Am 6-1-95

1 LOG RUN

2 LOG RUN

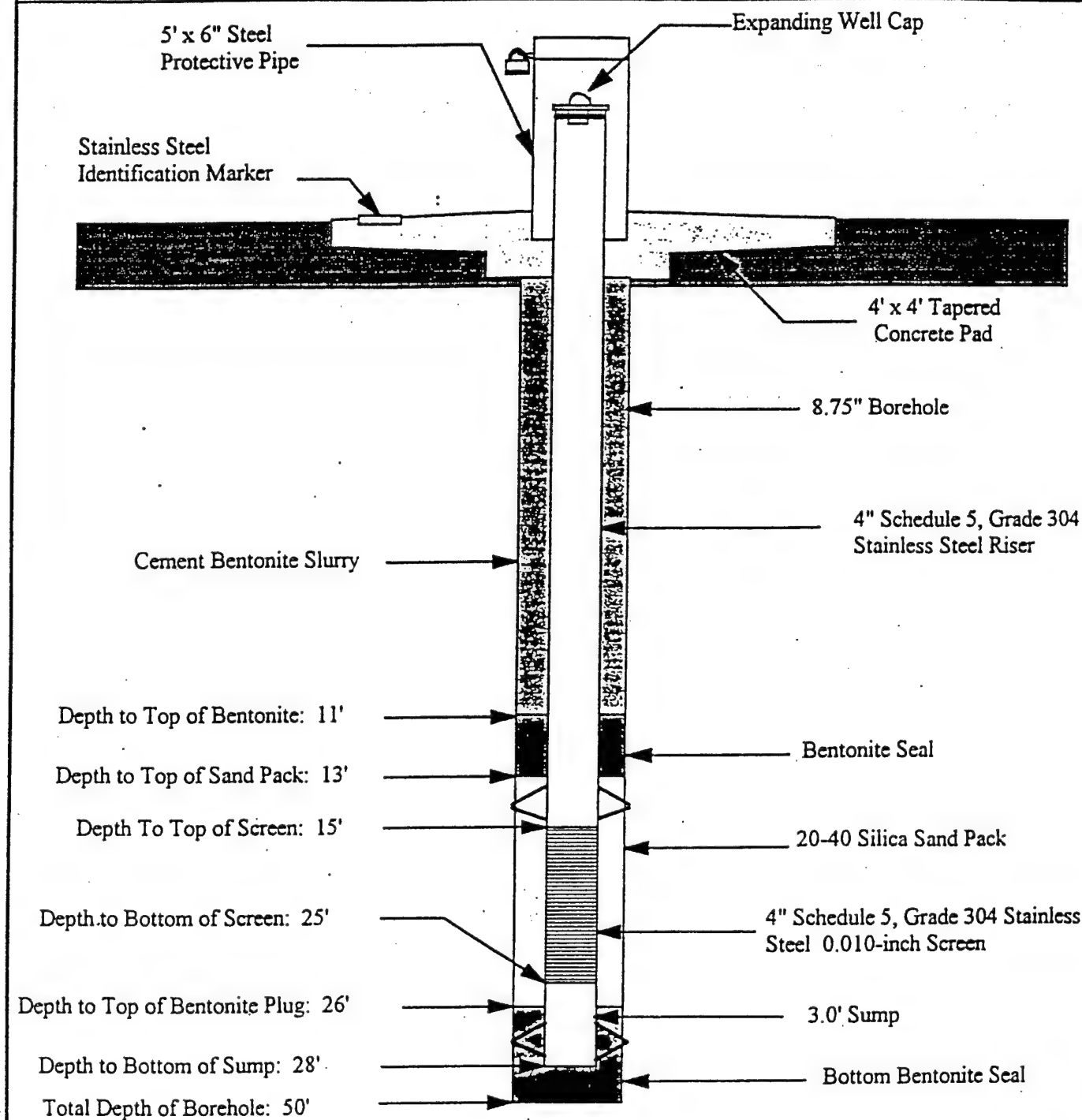
well Design Deliver
9:20 Am 6-1-95

WELL CONSTRUCTION SCHEMATIC

(2)

Client: Tinker Air Force Base	Well ID: 2-164B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/02/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): '
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): '
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos

Comments: Top Riser: 4" Schedule 40 PVC Casing. 2' thick top seal set.

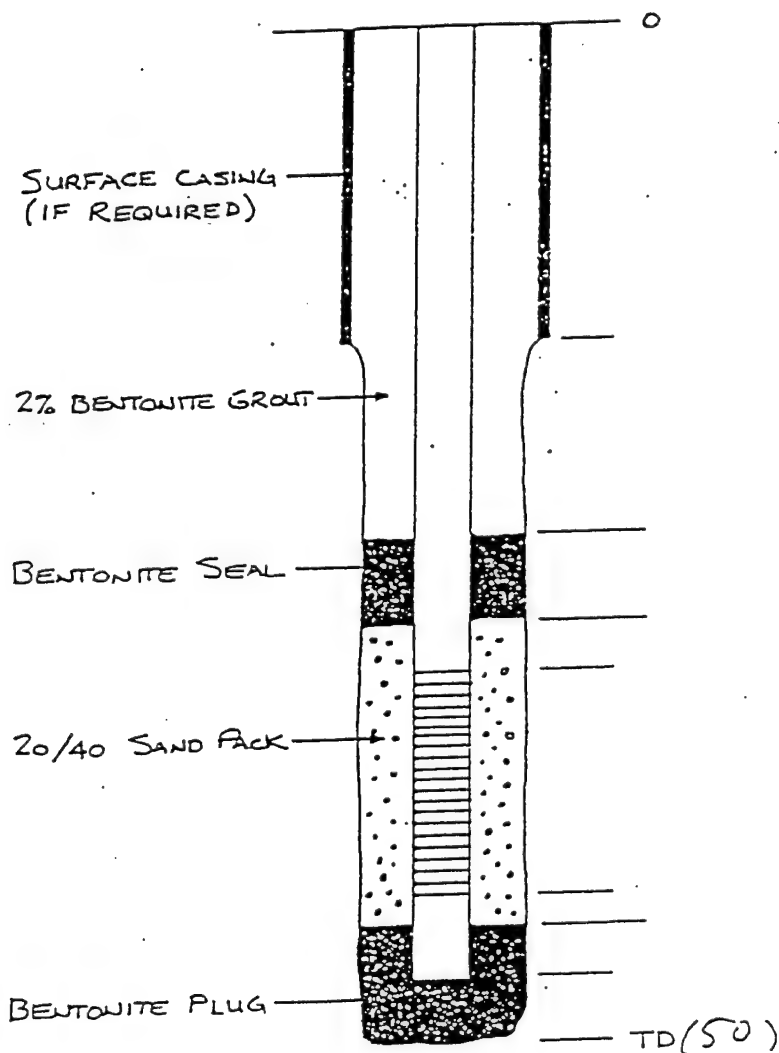


Drawing not to scale

< > Centralizers

2

Well ID	Recommended Construction		Comments
	Item	Depth	
2-164B	Surface Casing	—	
	Inner Casing	—	
	Grout	0 - 11	
	Bentonite Seal (top)	11 - 13	(2')
	Sand Pack	13 - 26	
	Bentonite Seal (bottom)	26 - TD	
	Riser	0 - 15	
	Screen	15 - 25	
	Sump	25 - 28	



Log Received

6-2-95 4:10

1 LOG RUN

2 LOG RUN

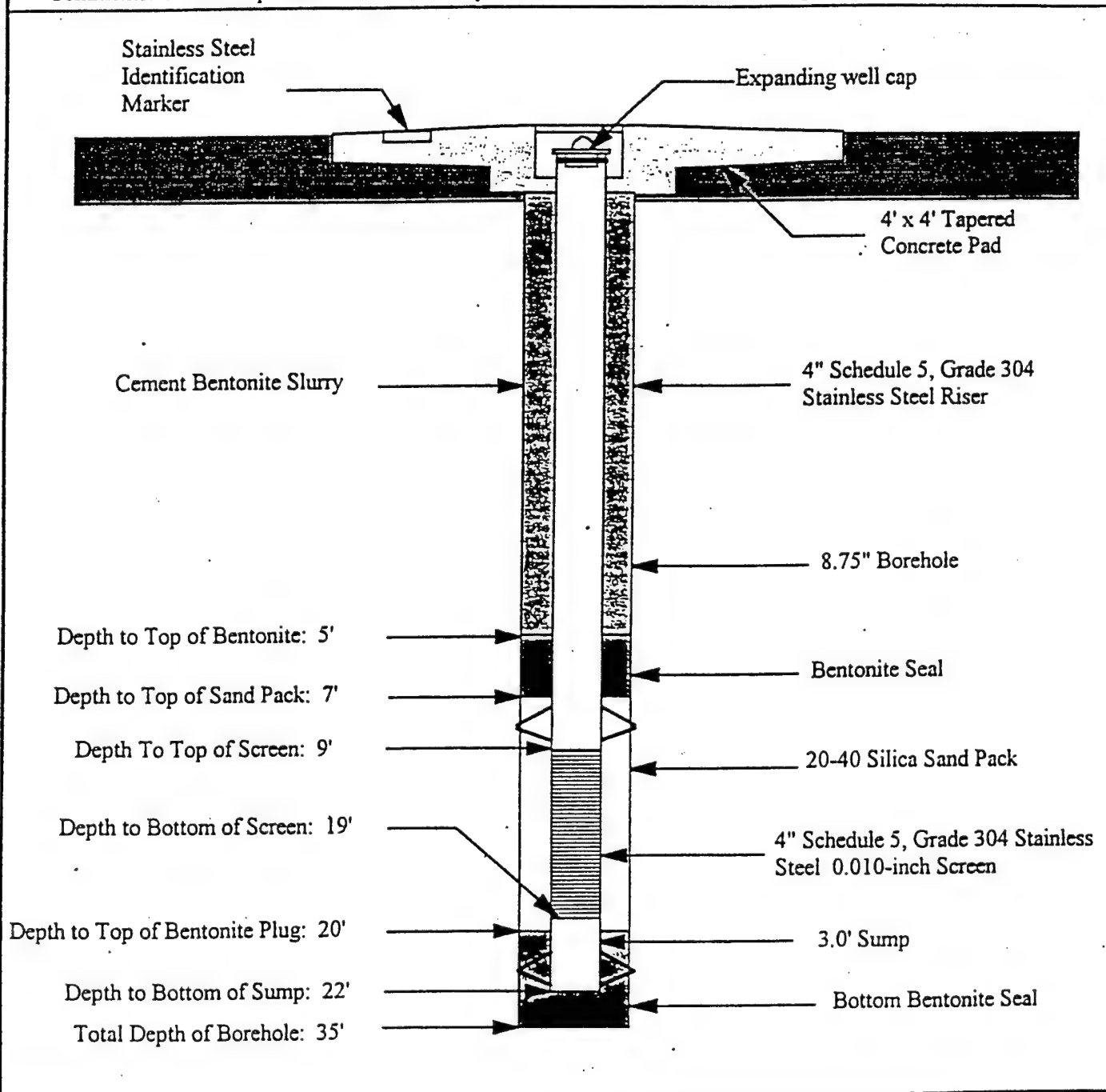
well Design Delivered

6-2-95 4:30

WELL CONSTRUCTION SCHEMATIC



Client: Tinker Air Force Base	Well ID: 2-165B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 06/07/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL):
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL):
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: 2' thick top bentonite seal set. Top Riser: 4" Schedule 40 PVC Casing.	



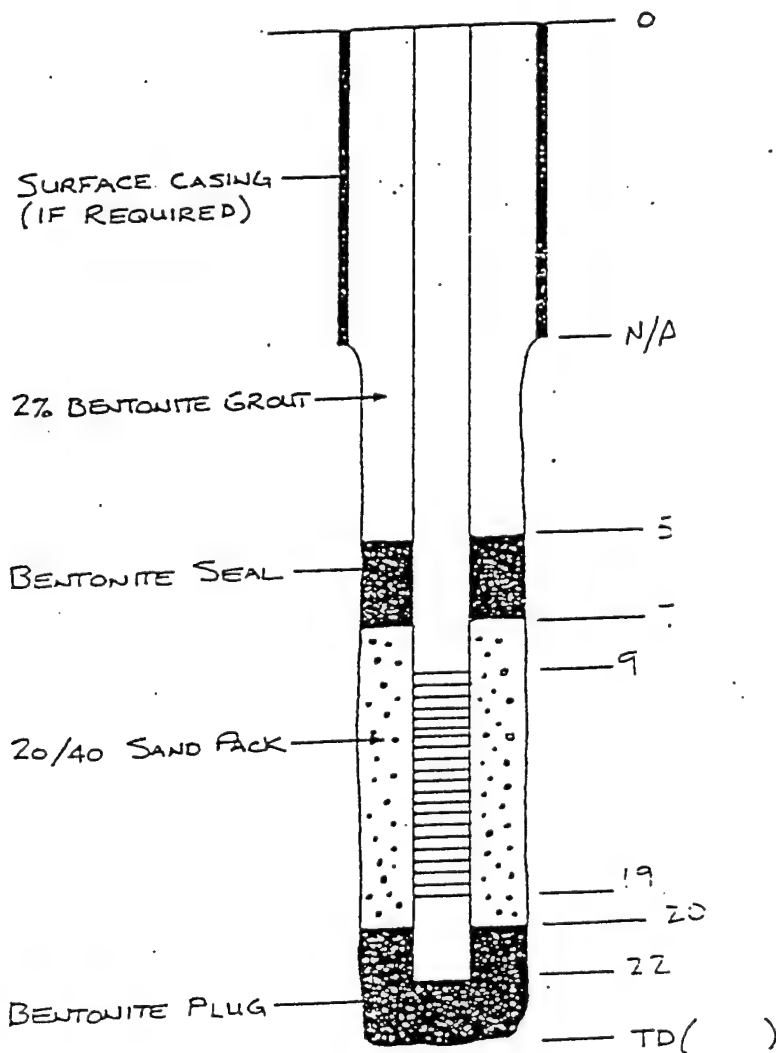
Drawing not to scale



Centralizers

A

Well ID	Recommended Construction		Comments
	Item	Depth	
Z-165B	Surface Casing	—	
	Inner Casing	—	
	Grout	0-5	
	Bentonite Seal (top)	5-7	
	Sand Pack	7-20	
	Bentonite Seal (bottom)	20-TD	
	Riser	0-9	
	Screen	9-19	
	Sump	19-22	



Log Received

1-7-92 2:00 PM

1 LOG RUN

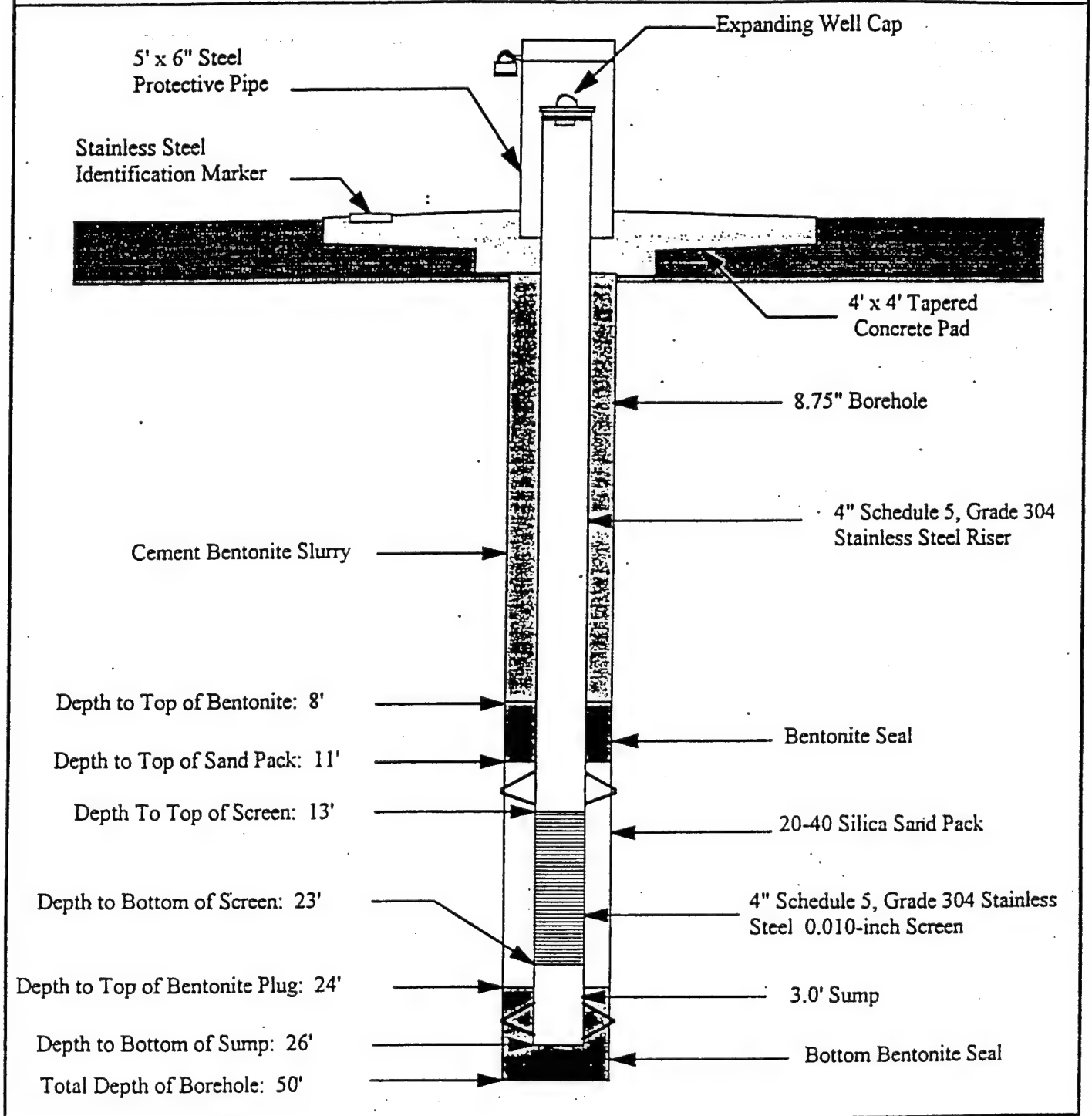
2 LOG RUN

Well Design Delivery
1-7-92 2:30 PM

WELL CONSTRUCTION SCHEMATIC

(12)

Client: Tinker Air Force Base	Well ID: 2-166B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/07/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): '
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): '
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: 3' thick top bentonite seal set. Top Riser: 4" Schedule 40 PVC Casing.	

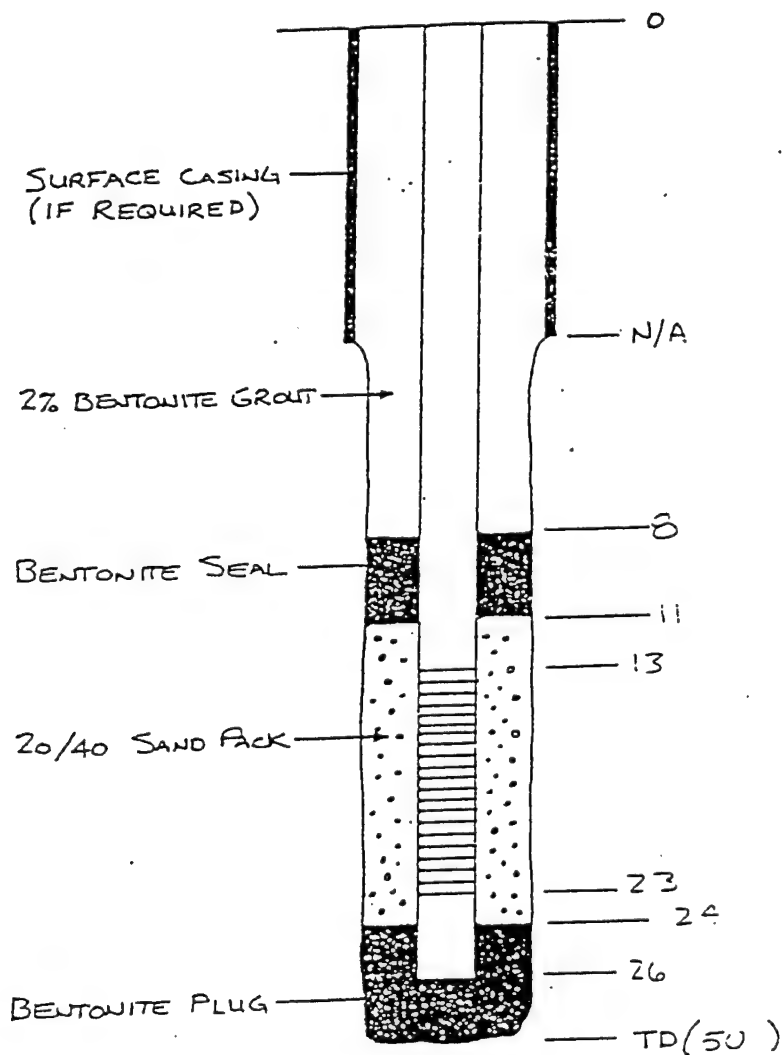


Drawing not to scale

< > Centralizers

R

Well ID	Recommended	Construction	Comments
	Item	Depth	
Z-166R	Surface Casing	—	
	Inner Casing	—	
	Grout	0-8	
	Bentonite Seal (top)	8-11	
	Sand Pack	11-24	
	Bentonite Seal (bottom)	24-TD	
	Riser	0-13	
	Screen	13-23	
	Sump	23-26	



Log Received

5-6-95

1 LOG RUN

2 LOG RUN

well Design Delivery

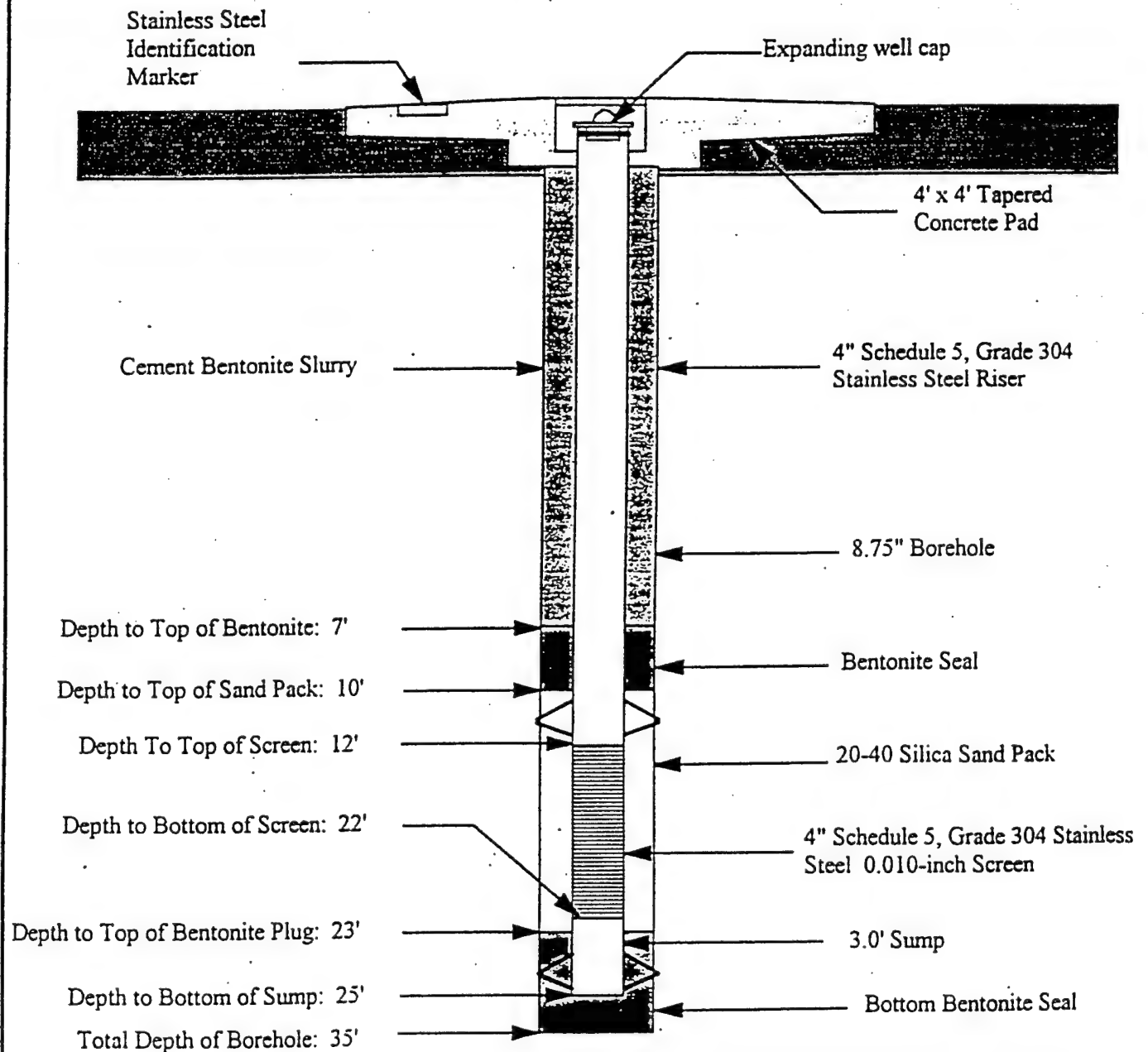
6-7-95 9:00 AM

WELL CONSTRUCTION SCHEMATIC



Client: Tinker Air Force Base	Well ID: 2-173B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 06/14/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL):
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL):
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos

Comments: Top Riser: 4" Schedule 40 PVC Casing. 3' thick top bentonite seal set.



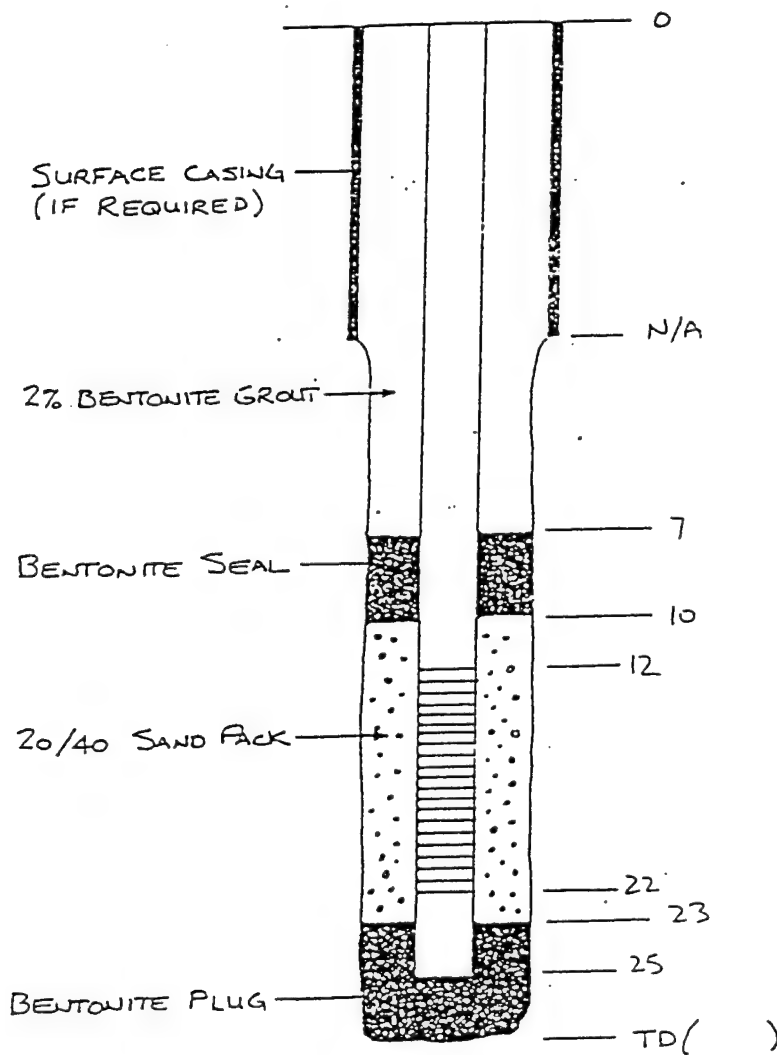
Drawing not to scale



Centralizers

2

Well ID	Recommended Construction		Comments
	Item	Depth	
2-173B	Surface Casing	-	
	Inner Casing	-	
	Grout	0-7	
	Bentonite Seal (top)	7-10	
	Sand Pack	10-23	
	Bentonite Seal (bottom)	23-TD	
	Riser	0-12	
	Screen	12-22	
	Sump	22-25	



Log Received

1-14-95 3:45

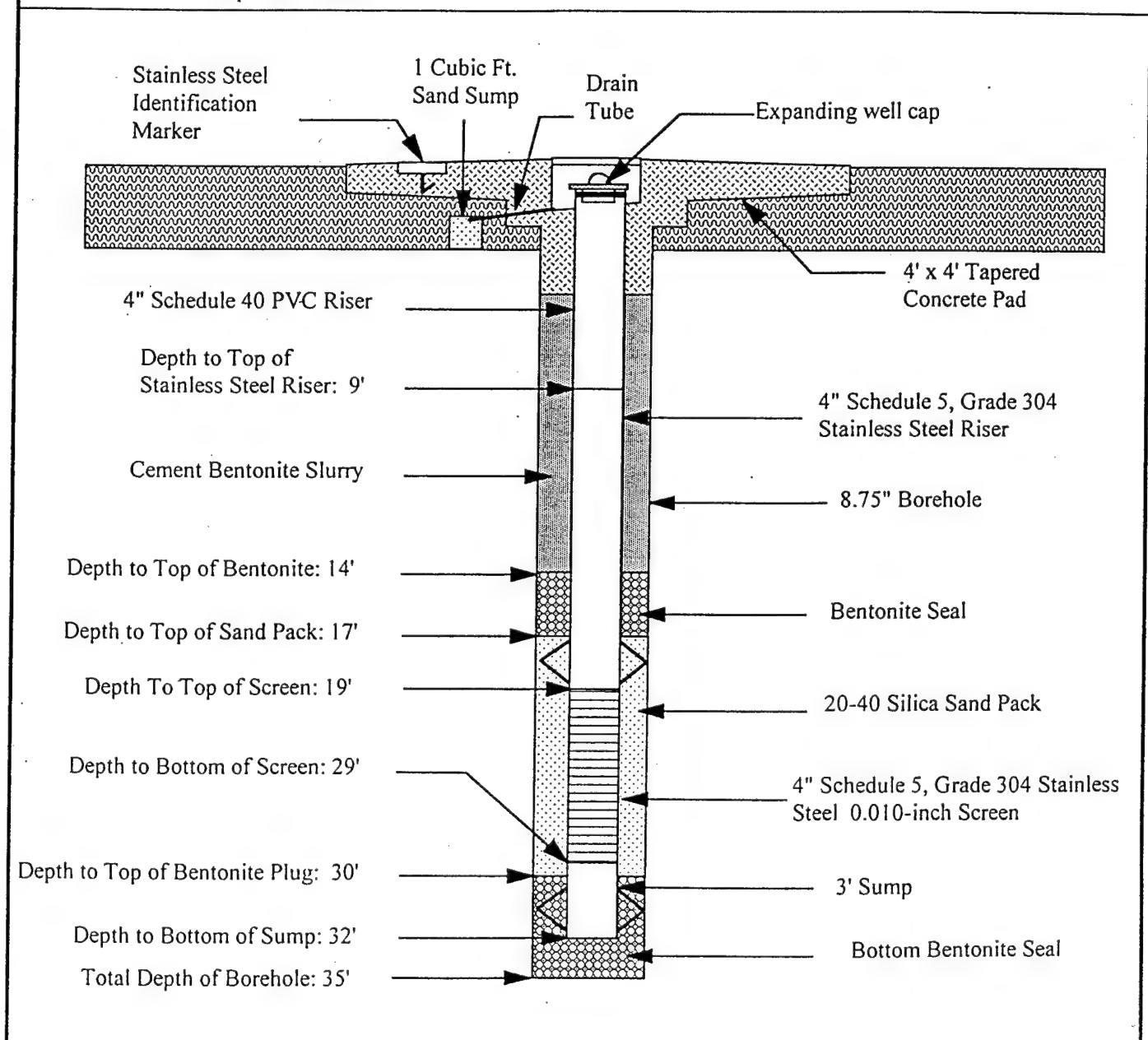
1 LOG RUN

2 LOG RUN

well Design Delivery
5-14-95 2:45

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-264B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 06/12/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,235.08'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,234.86'
Project Geologist: Steve Kelly	Northing Coordinate: 158,467.86'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,179,427.90'
Drilling Method: Hollow Stem Auger	Permanent Monuments Used in Survey: SE53, PR11
Dedicated Pump: 2-inch Grundfos	Legal Description: NW/4 Section 15, T11N, R2W
Comments: 3' thick top bentonite seal set.	

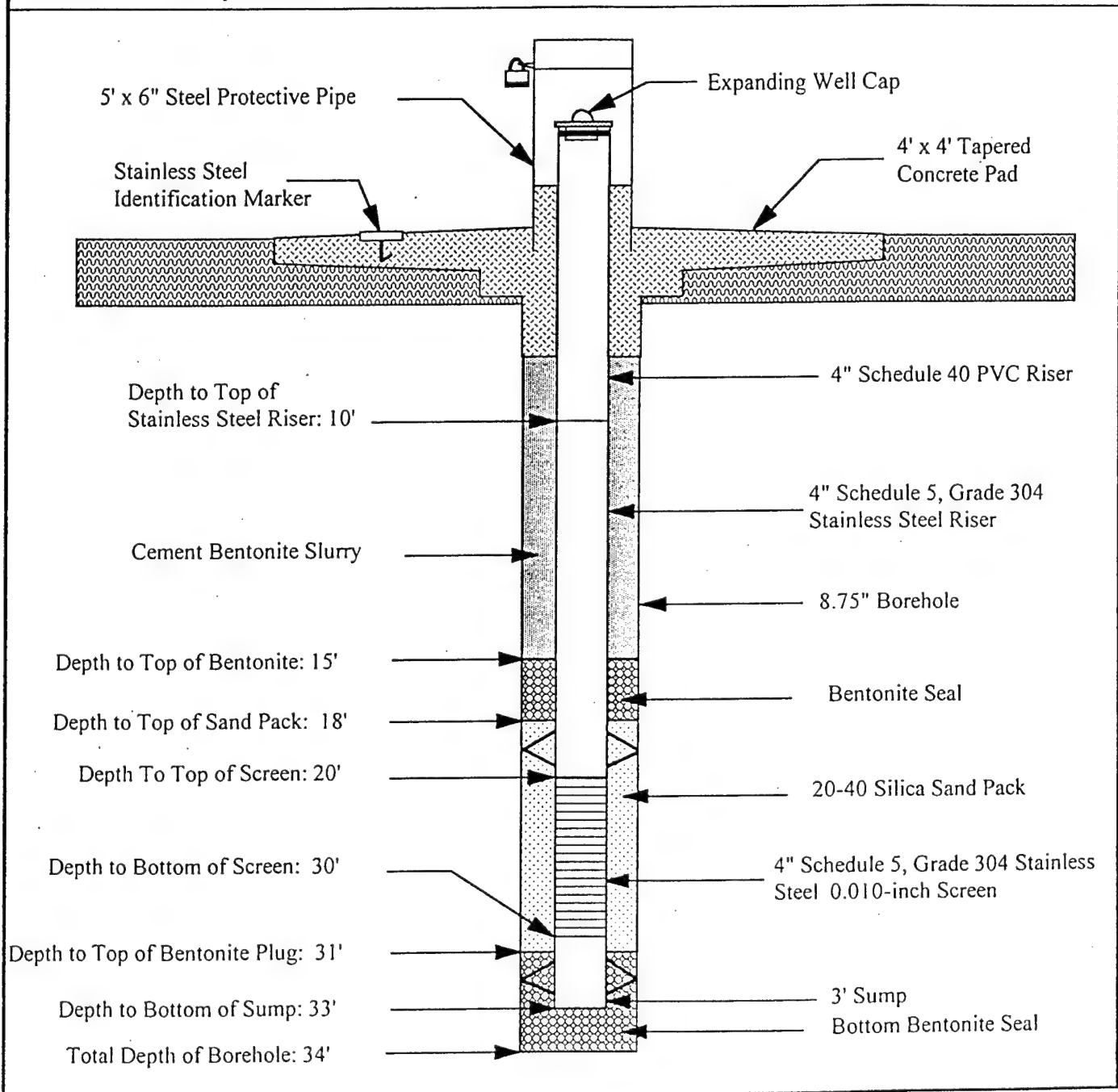


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

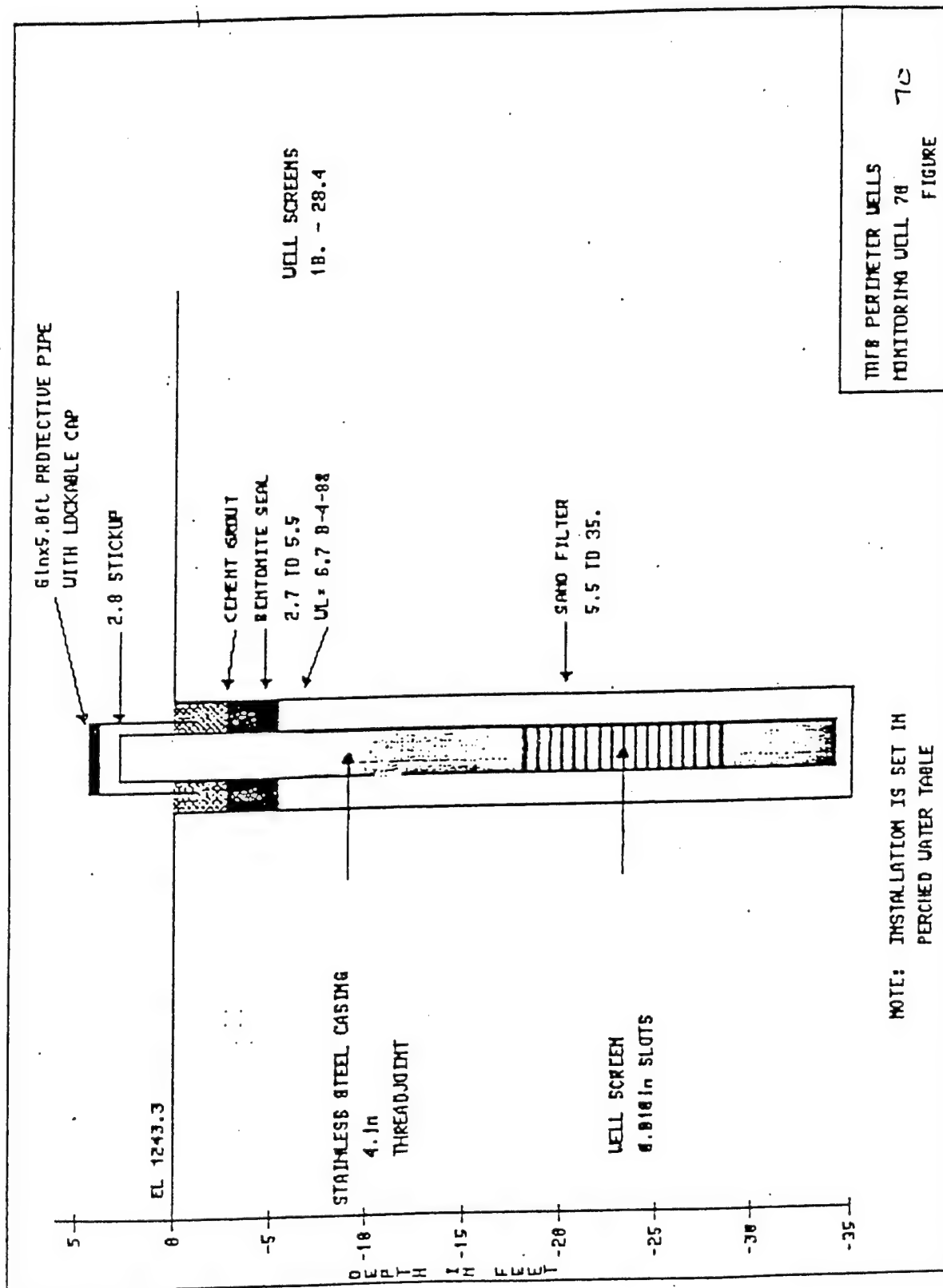
Client: Tinker Air Force Base	Well ID: 2-265B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 06/12/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,234.13'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,236.63'
Project Geologist: Steve Kelly	Northing Coordinate: 158,291.51'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,179,373.38'
Drilling Method: Hollow Stem Auger	Permanent Monuments used in Survey: SE53, PR11
Dedicated Pump: 2-inch Grundfos	Legal Description: NW/4 Section 15 T11N, R2W
Comments: 3' thick top bentonite seal set.	



Drawing not to scale

< > Centralizers

DRILLING LOG		DIVISION	SOUTHWEST		INSTALLATION	TANKER AFB		SHEET	1	OF 1 SHEETS	
1. PROJECT					PERIMETER MONITORING WELLS						
2. LOCATION (Coordinates or Station)					158485.40 2180809.30						
3. DRILLING AGENCY					TULSA DISTRICT						
4. HOLE NO. (As shown on drawing title and the number)					MW-70						
5. NAME OF DRILLER					JAMES WYATT						
6. DIRECTION OF HOLE					DO VERTICAL						
7. THICKNESS OF OVERBURDEN					8.0						
8. DEPTH DRILLED INTO ROCK					27.0						
9. TOTAL DEPTH OF HOLE					35.0						
10. SIZE AND TYPE OF BIT					6" A 9.5" RB						
11. DATUM FOR ELEVATION SHOWN (Top of HSE)					MSL						
12. MANUFACTURER'S DESIGNATION OF DRILL					ONE						
13. TOTAL NO OF OVER-BURDEN SAMPLES TAKEN					DISTURBED		0		UNDISTURBED		0
14. TOTAL NUMBER CORE BOXES					0						
15. ELEVATION GROUND WATER					7.0'		(5 NOV 87)				
16. DATE HOLE					STARTED		10/29/1987		COMPLETED		10/29/1987
17. ELEVATION TOP OF HOLE					1243.3						
18. TOTAL CORE RECOVERY FOR BORING					0.0						
19. SIGNATURE OF INSPECTOR					CARL NARDIN						
ELEVATION	DEPTH	LEGEND	CLASSIFICATION OF MATERIALS (Description)			% CORE RECOVERY	BOX OR SAMPLE NO.	REMARKS (Logging data, water level, depth of casing, etc., if significant)			
1233.1			CLAY (CL) (0.0 - 0.4)					AUGERED W/6" BIT TO WATER @ 25.0', ROCKBIT TO 35.0' WITH 9 1/2" BIT. MEASURED WATER LEVEL AT 7.0' ON 5 NOV 87. SET 37.0' OF 4" STAINLESS STEEL CASING WITH SCREEN FROM 28.2 TO 17.8' AND A 5.8' SUMP. SAND FILTER TO 5.5', SEAL TO 2.7'. BAILED INSIDE PIPE AND FLUSHED WITH FRESH WATER.			
1232.5			TOPSOIL, DK-BROWN, DRY								
			CONCRETE (C) (0.4 - 1.0)								
	2		CLAY (CL) (1.0 - 4.0)								
			SILTY, SOFT, LOW PLAST., RED-BROWN, SL. MOIST								
1229.5	4		SAND (SC) (4.0 - 8.0)								
			CLAYEY, V. FINE, LOOSE, GRAY-BROWN, SL. MOIST								
1225.5	8		SANDSTONE (SS) (8.0 - 35.0)								
			SHALEY, LOOSELY CEMENTED, V. FINE, RED-BROWN, OCCASIONALLY SPECKLED W/ GREEN-GRAY, SL. MOIST 8.0' TO 15.0' WET @ 15.0'								
1223.3	20		BOTTOM OF HOLE AT 35.0'								

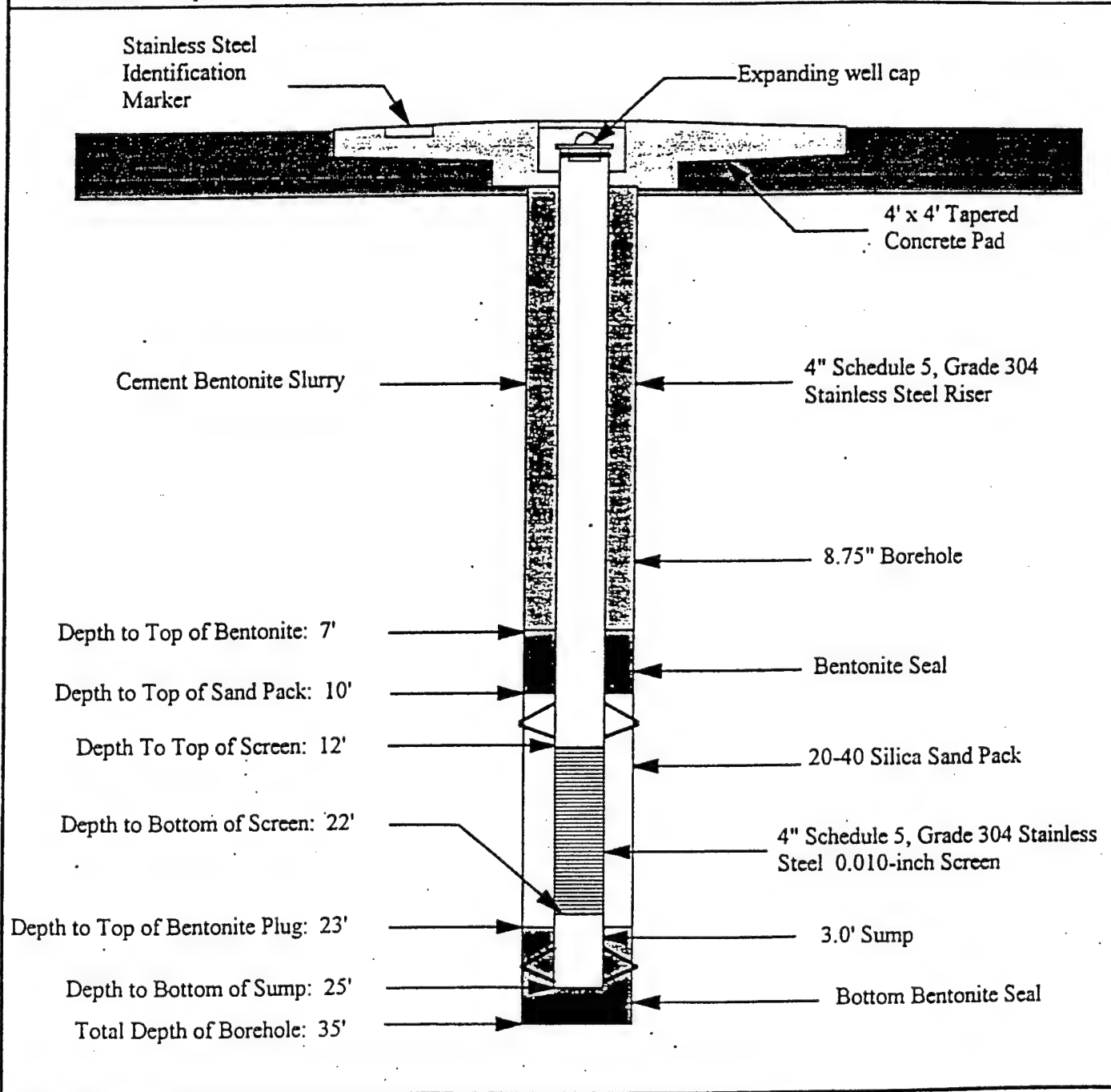


12

WELL CONSTRUCTION SCHEMATIC

(2)

Client: Tinker Air Force Base	Well ID: 2-146B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 06/13/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL):
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL):
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing. 3' thick top bentonite seal set.	



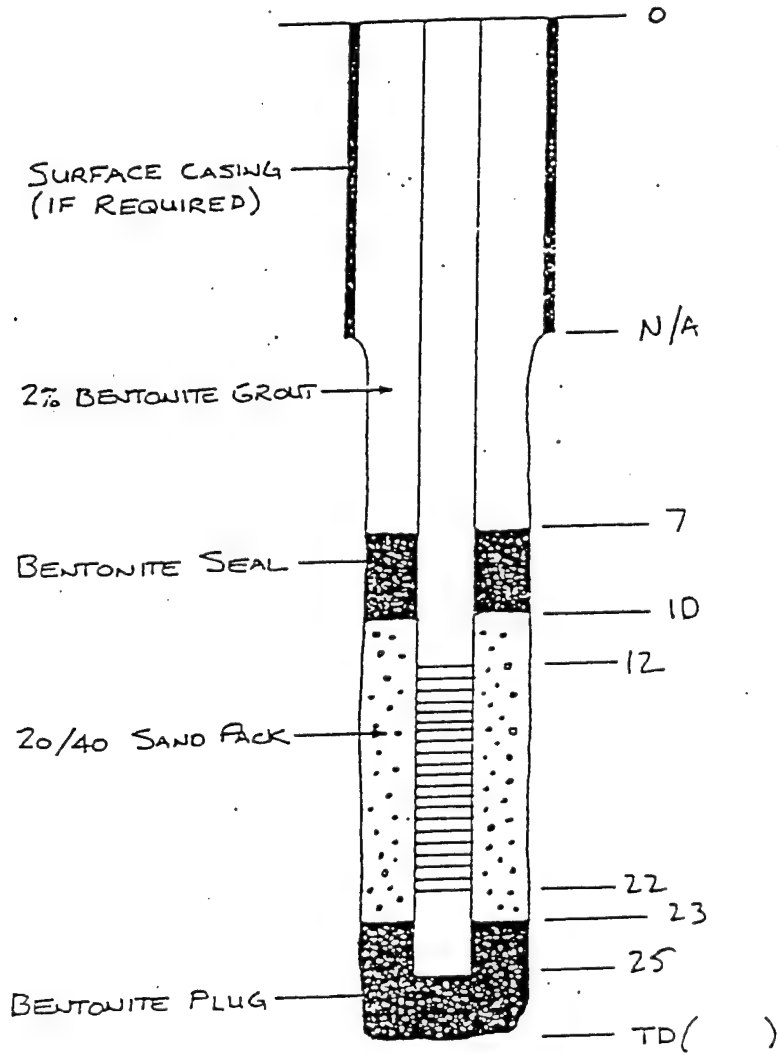
Drawing not to scale.



Centralizers

2

Well ID	Recommended Construction		Comments
	Item	Depth	
2-146B	Surface Casing	—	
	Inner Casing	—	
	Grout	0-7	
	Bentonite Seal (top)	7-10	
	Sand Pack	10-23	
	Bentonite Seal (bottom)	23-TD	
	Riser	0-12	
	Screen	12-22	
	Sump	22-25	



Log Received

well Design Delivery

12-14-95 2:21

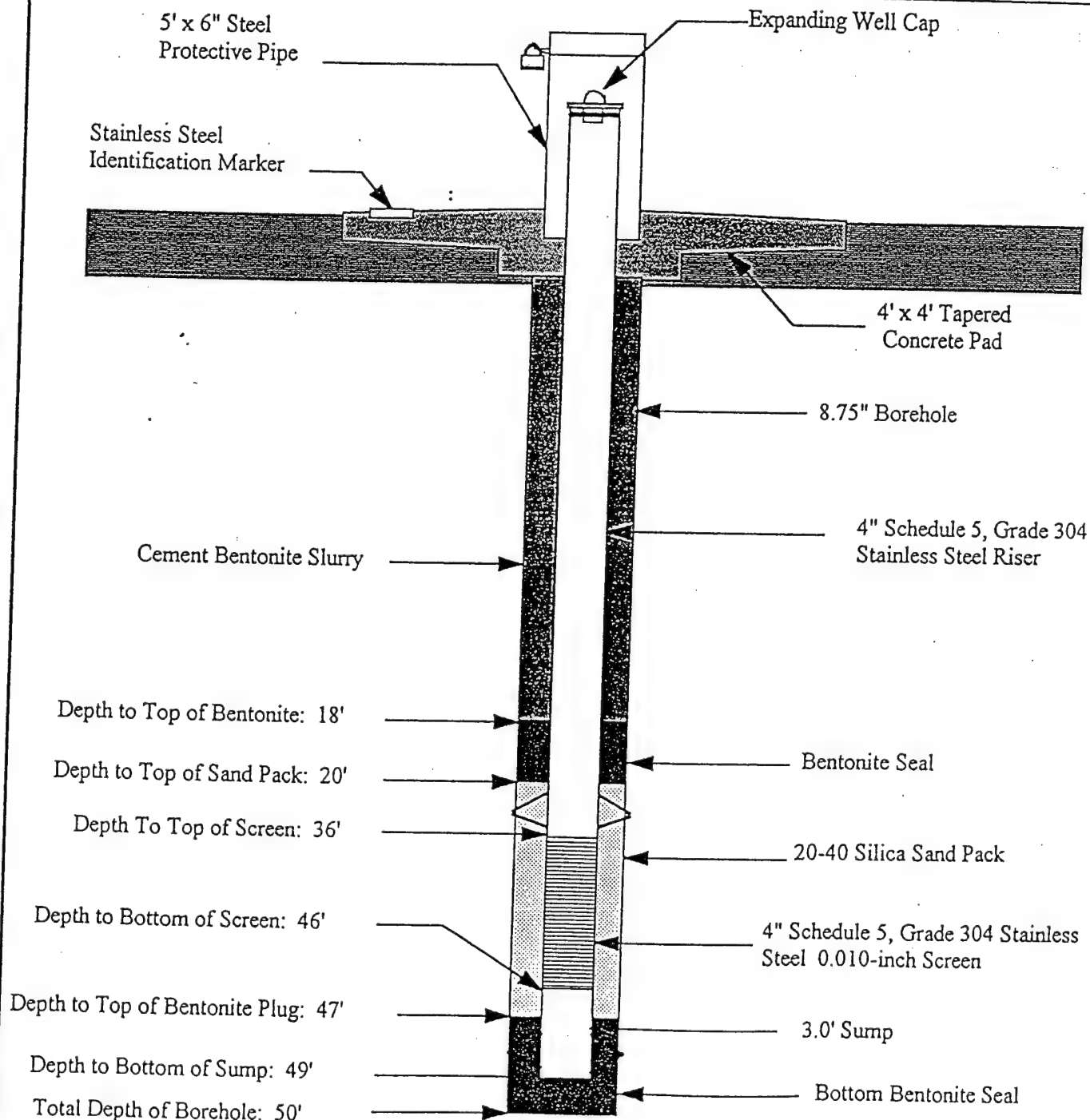
12-14-95 3:45

1 LOG RUN

2 LOG RUN

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-147B
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 02/03/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1268.63'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1271.83'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Riser Casing. 2' thick top seal. Top of sand set 16' above screen.	

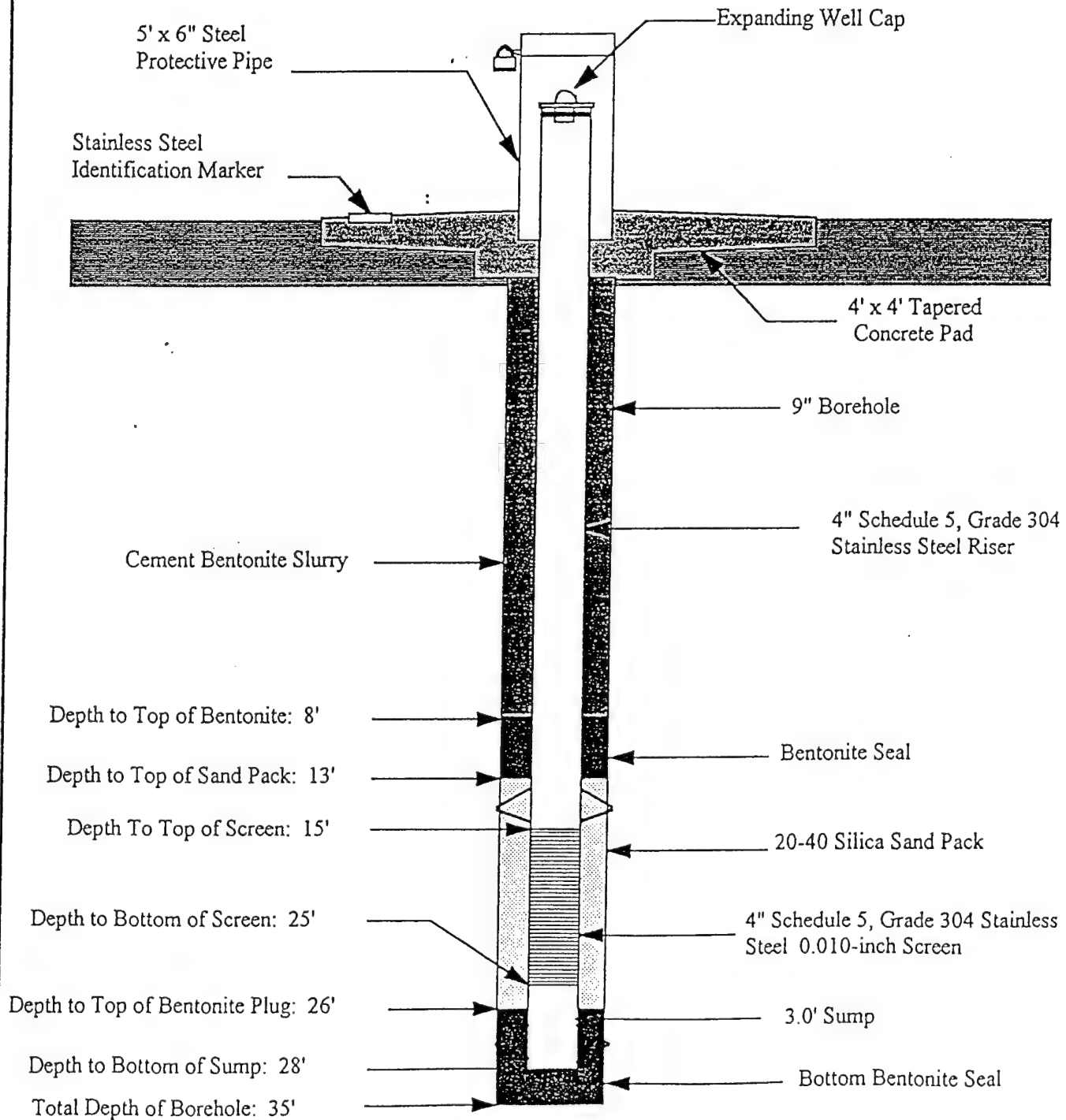


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-148B
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/20/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1247.46'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1250.12'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments:	

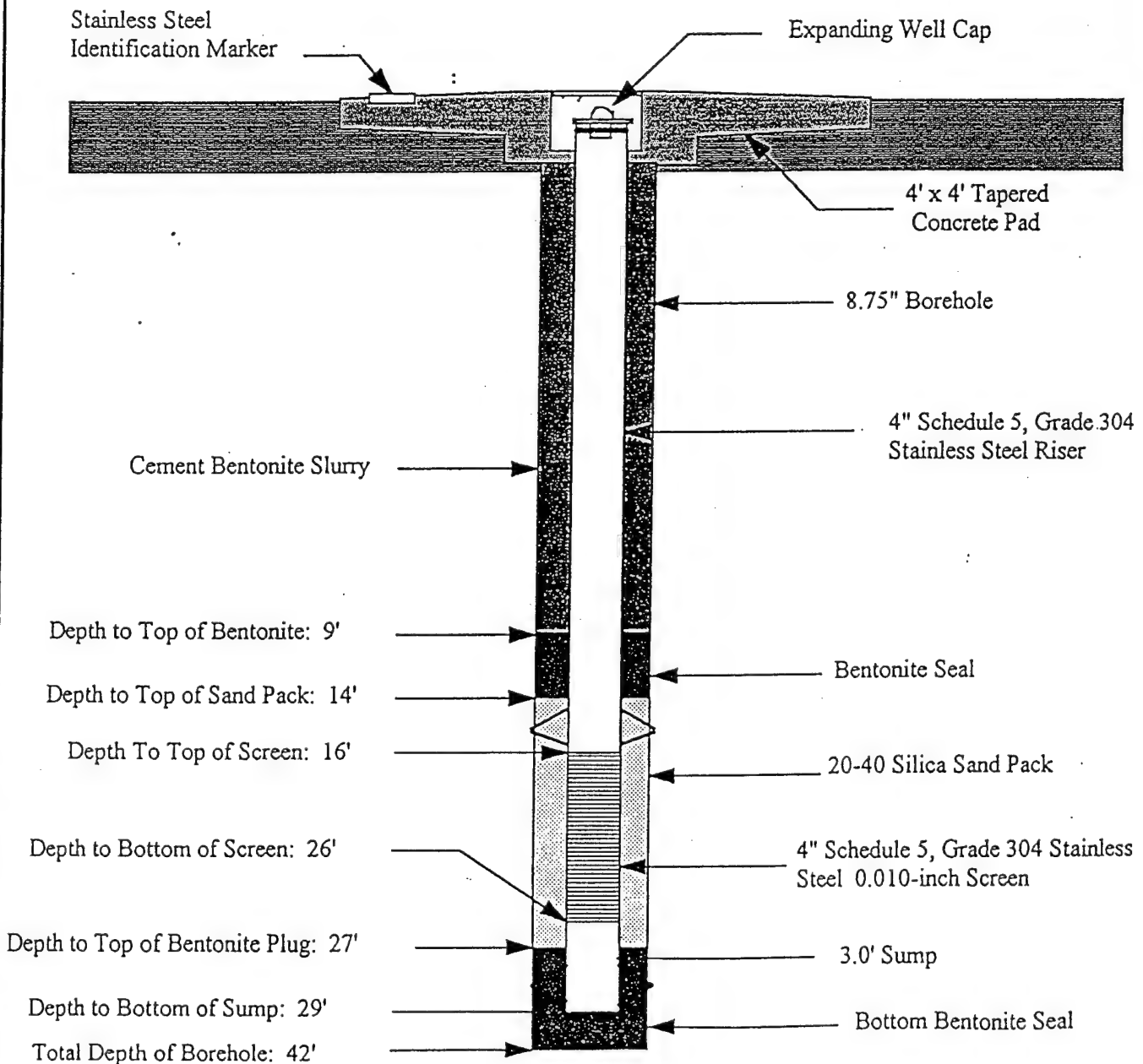


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-149B
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/07/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1237.08'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1236.55'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	

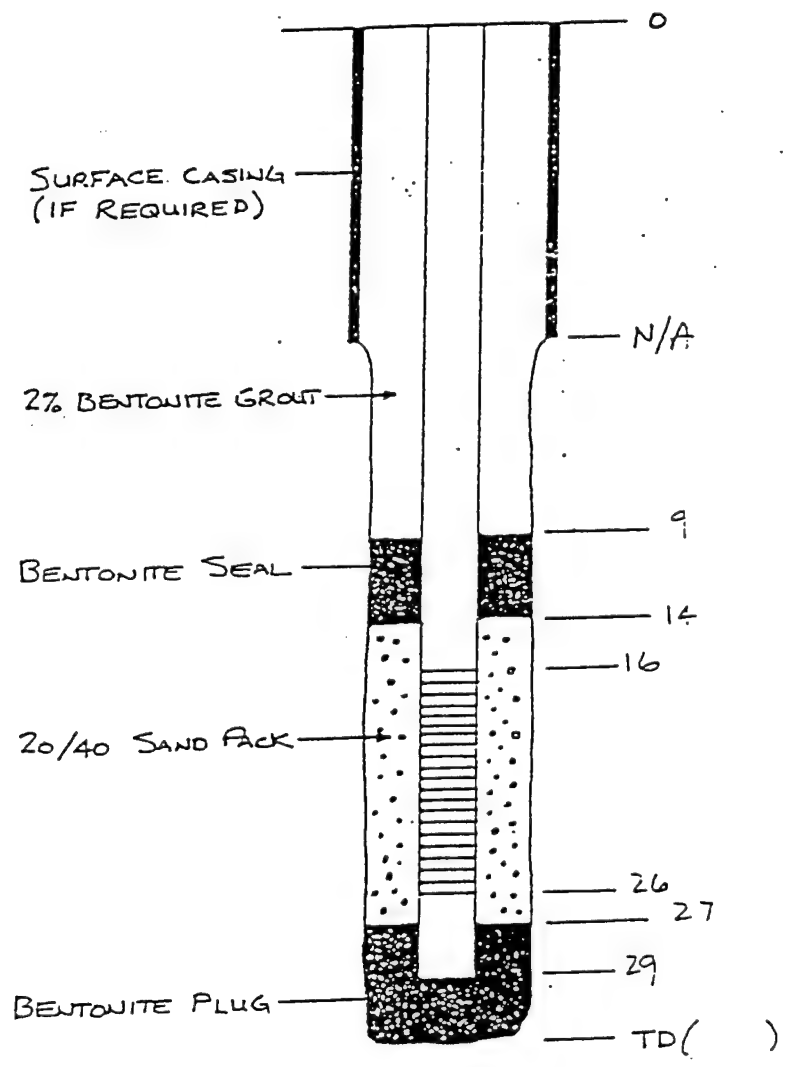


Drawing not to scale

< > Centralizers

12

Well ID	Recommended Construction		Comments
	Item	Depth	
Z-149B	Surface Casing	—	
	Inner Casing	—	
	Grout	0-9	
	Bentonite Seal (top)	9-14	
	Sand Pack	14-27	
	Bentonite Seal (bottom)	27-TD	
	Riser	0-16	
	Screen	16-26	
	Sump	26-29	



Log Received _____

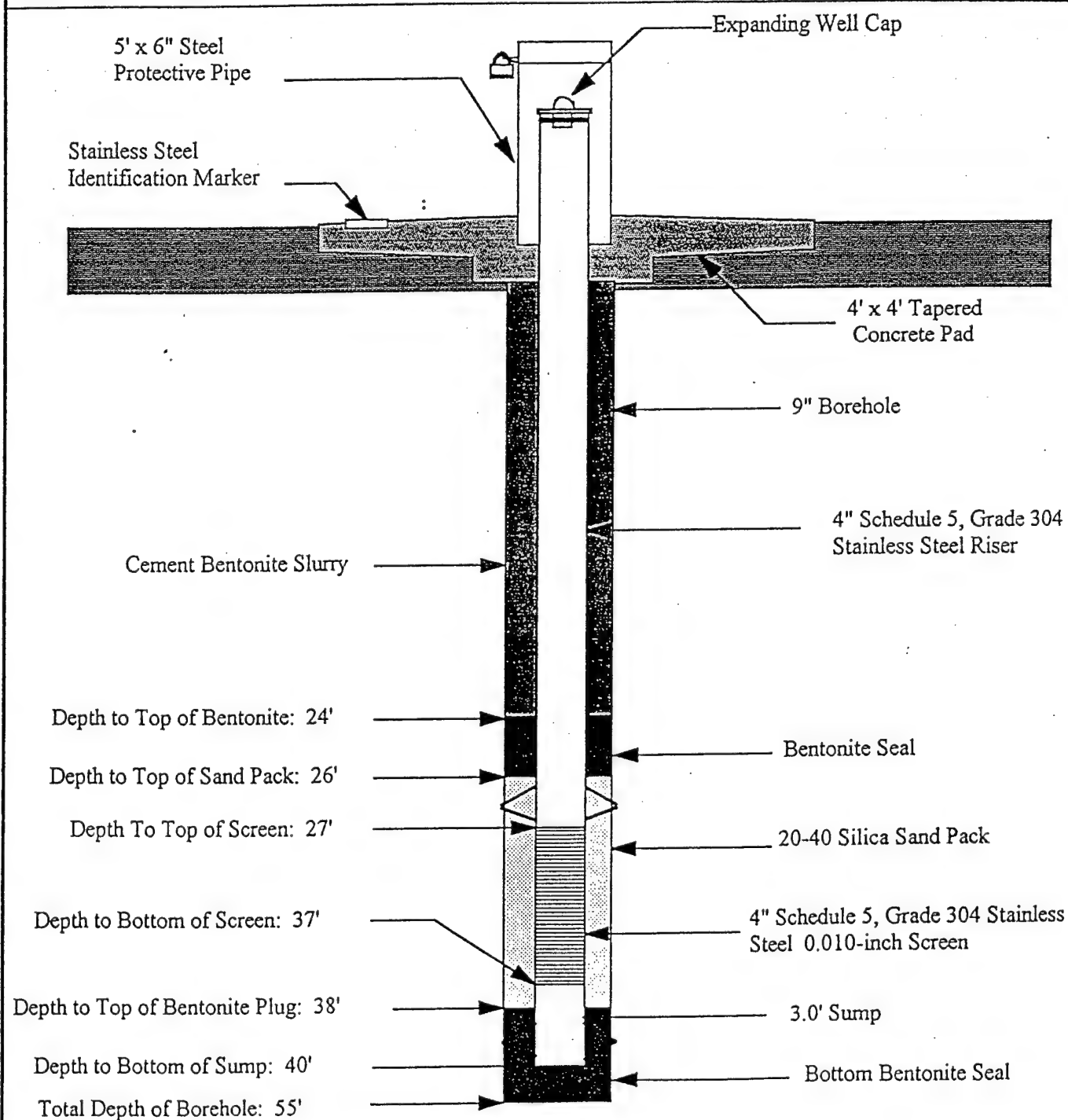
_____ 1 LOG RUN _____

_____ 2 LOG RUN _____

Well Design Delivery
1-7-95

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-150B
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/10/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1231.40'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1234.03'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing. 2' thick top seal set. Top of sand placed 1' above screen.	



Drawing not to scale

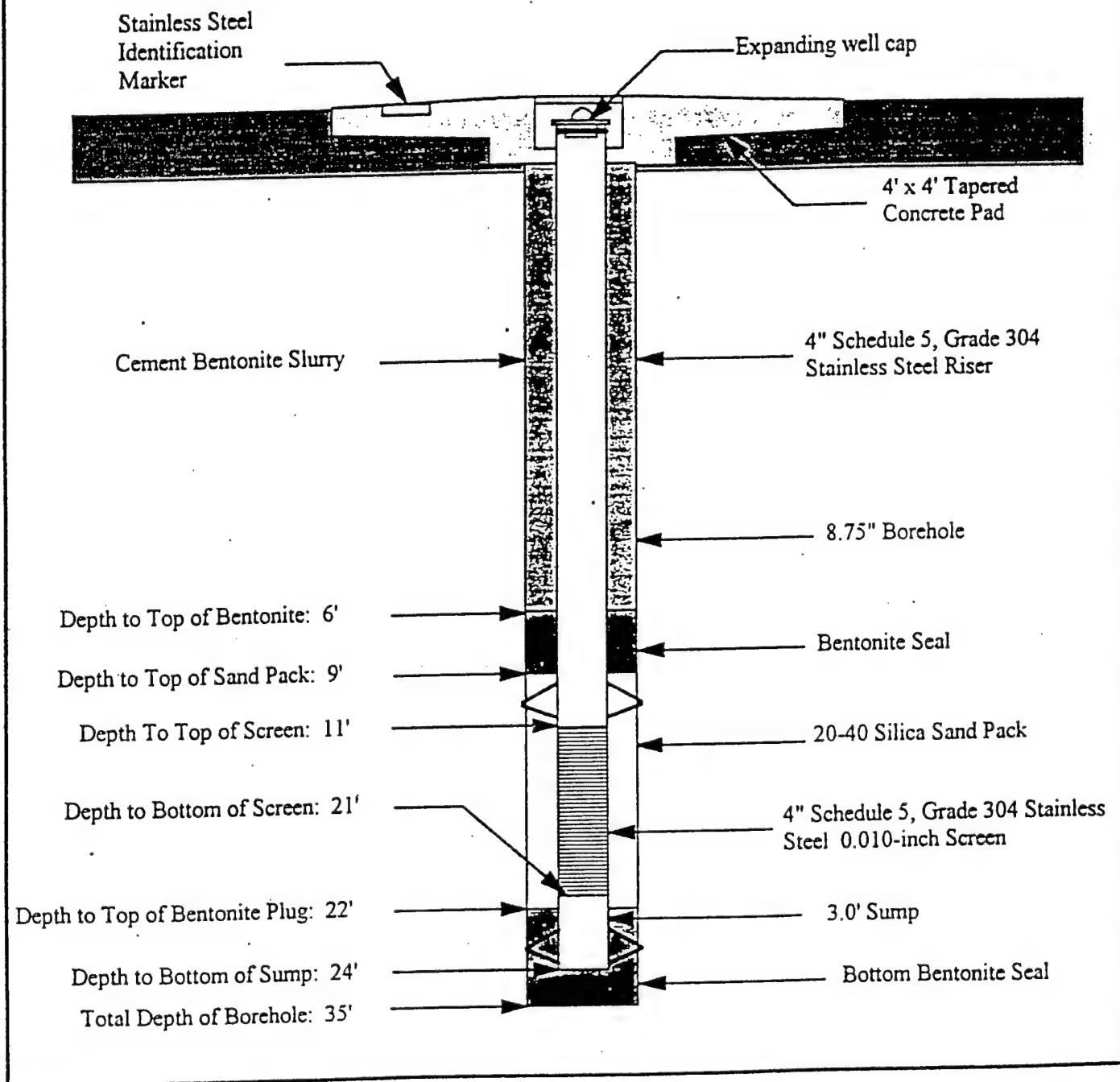
< > Centralizers

WELL CONSTRUCTION SCHEMATIC

(2)

Client: Tinker Air Force Base	Well ID: 2-145B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 06/14/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL):
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL):
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos

Comments: Top Riser: 4" Schedule 40 PVC Casing. 3' thick top bentonite seal set.



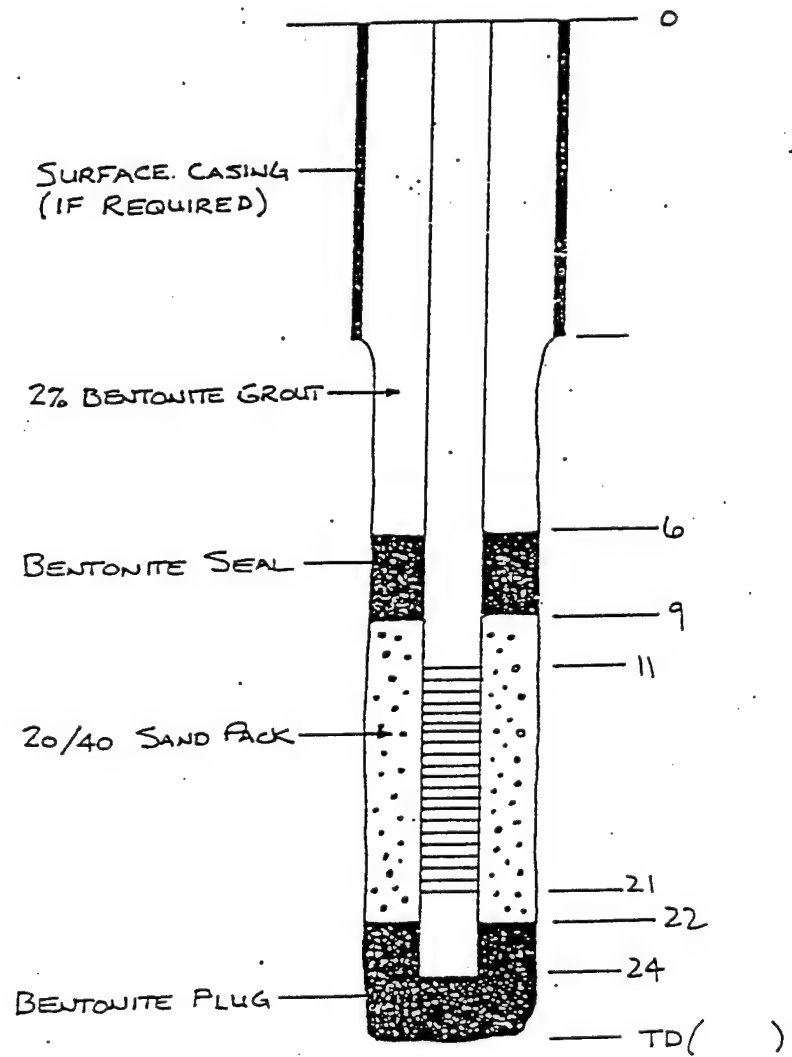
Drawing not to scale



Centralizers

12

Well ID	Recommended Construction		Comments
	Item	Depth	
2-145B	Surface Casing	—	
	Inner Casing	—	
	Grout	0-6	
	Bentonite Seal (top)	6-9	
	Sand Pack	9-22	
	Bentonite Seal (bottom)	22-TD	
	Riser	0-11	
	Screen	11-21	
	Sump	21-24	



Log Received
6-14-95

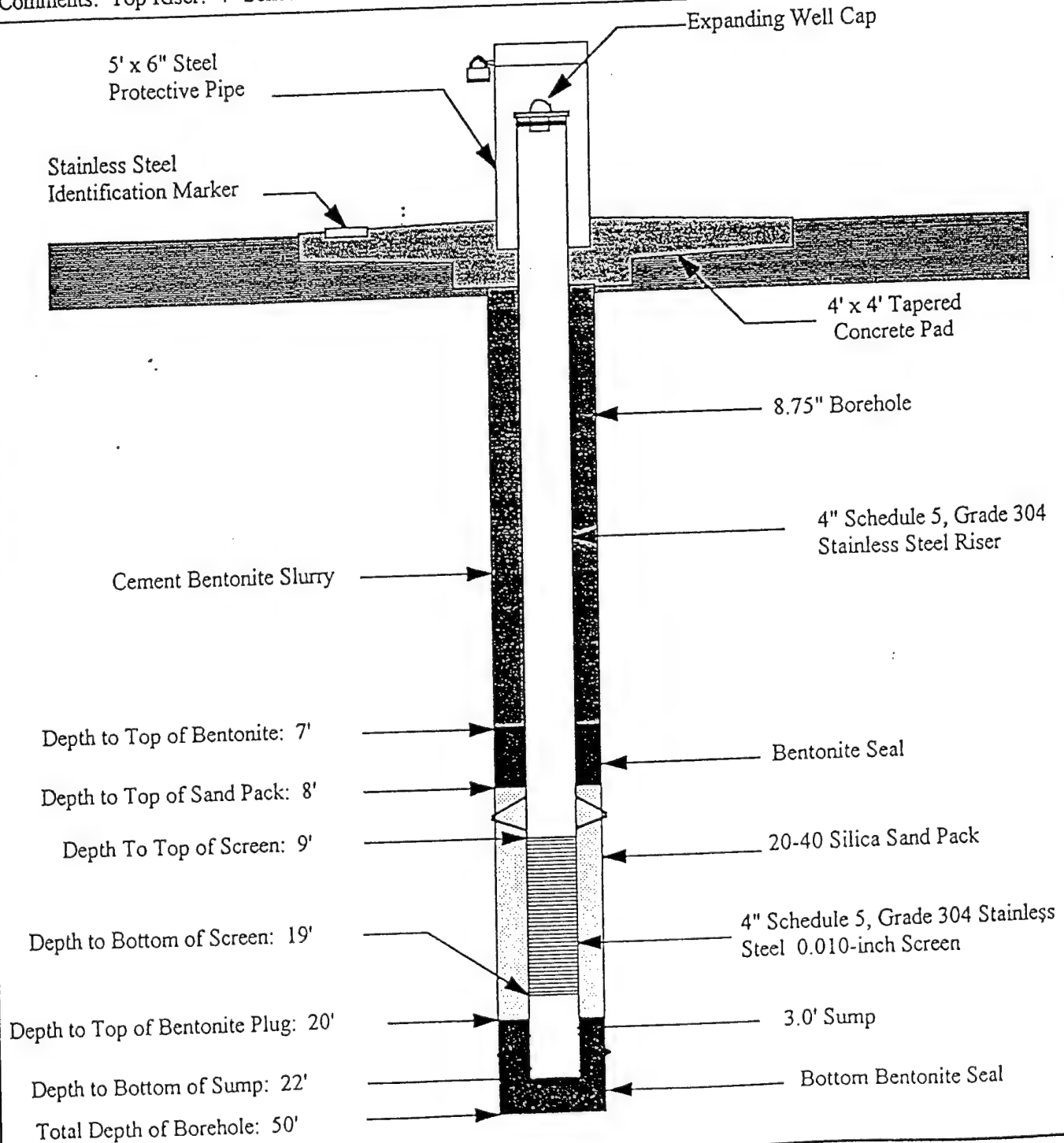
1 LOG RUN

2 LOG RUN

Well Design Delivered
6-12-95

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-152B
Location: TAFB, Oklahoma	Site: BW
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/18/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1243.46'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1246.06'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing. 1' thick top seal set. Top of sand set 1' above screen.	



Drawing not to scale

< > Centralizers

Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

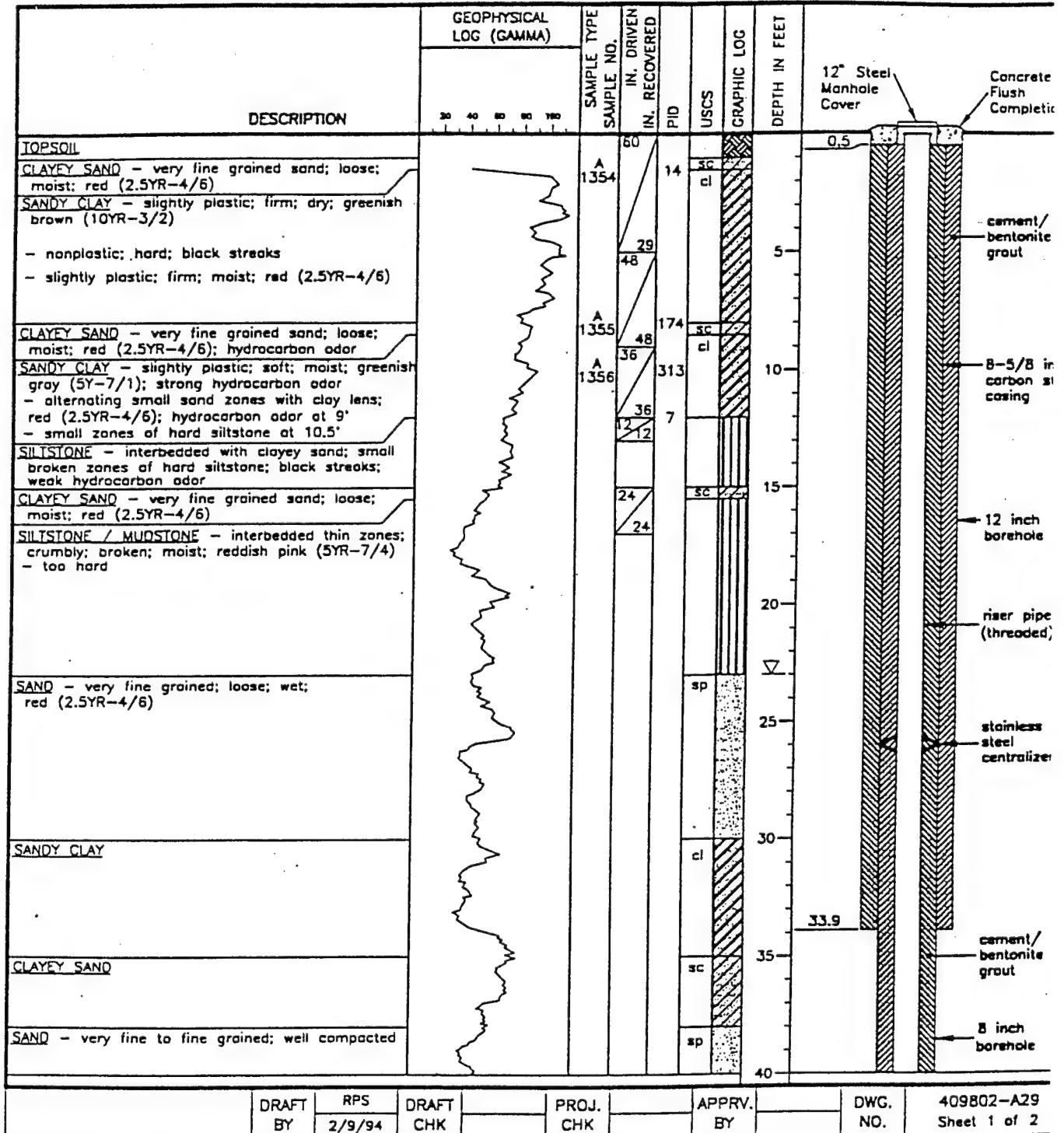
MONITORING WELL 2-

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A PAD ELEV.(FT): 1240.51
TOTAL DEPTH(FT.): 70.5
Logged By: V. CRNICH, P. SCHUMANN Date Started: 11/9/93
Drilled By: T. PATTERSON, NESCO Date Completed: 11/24/93
A. SORIANO, GPI
Drill Rig Type: SIMCO, MOBILE B-61
Drilling Method: HOLLOW STEM AUGER
AND MUD ROTARY
Sampling Method: CONTINUOUS SAMPLER
Notes: 6" AND 8" BOREHOLE; DESCRIPTIONS BELOW 40'
PARTIALLY BASED ON GAMMA LOG
COORDINATES--NAD 27: N 158259.233, E 2180356.152

WELL COMPLETION DATA

Elev--Top of Casing(ft.): 1242.96 Ref. Datum: NGVD
1. Surf Casing--LD.(in.): 8-5/8 Depth(ft.): 33.9 Type: Carbon
Centralizers--Type: Depths(ft.):
2. Riser Pipe--LD.(in.): 2 Depth(ft.): 60.0 Type: S.Steel
Centralizers--Type: S.Steel Depths(ft.): 26.0, 59.0
3. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(ft.): 60.0-70.0 Slot Size(in.): .010
Centralizers--Type: Depths(ft.):
4. Filter Pack Type: Silica Sand Depth Interval(ft.): 58.0-70.5
Conc. Pad Size: 4'x4'x6"



Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

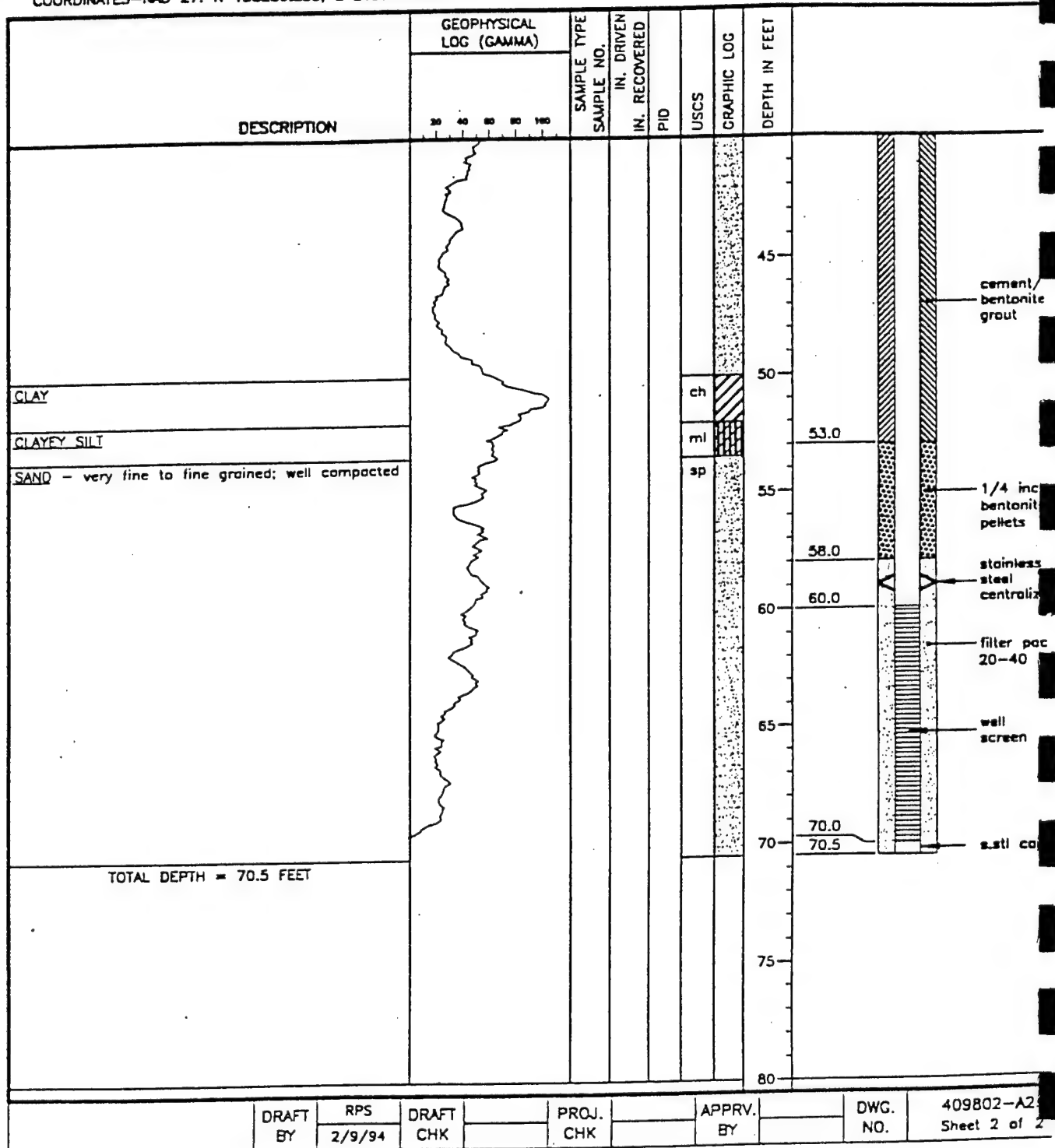
2-2A
MONITORING WELL 2-

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A PAD ELEV.(FT): 1240.51
TOTAL DEPTH(FT.): 70.5
Logged By: V. CRNICH, P. SCHUMANN Date Started: 11/9/93
Drilled By: T. PATTERSON, NESCO Date Completed: 11/24/93
A. SORIANO, GPI
Drill Rig Type: SIMCO, MOBILE B-61
Drilling Method: HOLLOW STEM AUGER
AND MUD ROTARY
Sampling Method: CONTINUOUS SAMPLER
Notes: 6" AND 8" BOREHOLE; DESCRIPTIONS BELOW 40'
PARTIALLY BASED ON GAMMA LOG
COORDINATES—NAD 27: N 158259.233, E 2180356.152

WELL COMPLETION DATA

Elev—Top of Casing(FL): 1242.96 Ref. Datum: NGVD
1. Surf Casing—LD.(in.): 8-5/8 Depth(FL): 33.9 Type: Carbon
Centralizers—Type: Depths(FL):
2. Riser Pipe—LD.(in.): 2 Depth(FL): 60.0 Type: S.Steel
Centralizers—Type: S.Steel Depths(FL): 26.0, 59.0
3. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(FL): 60.0-70.0 Slot Size(in.): .010
Centralizers—Type: Depths(FL):
4. Filter Pack Type: Silica Sand Depth Interval(FL): 58.0-70.5
Conc. Pad Size: 4"x4"x6"



Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-

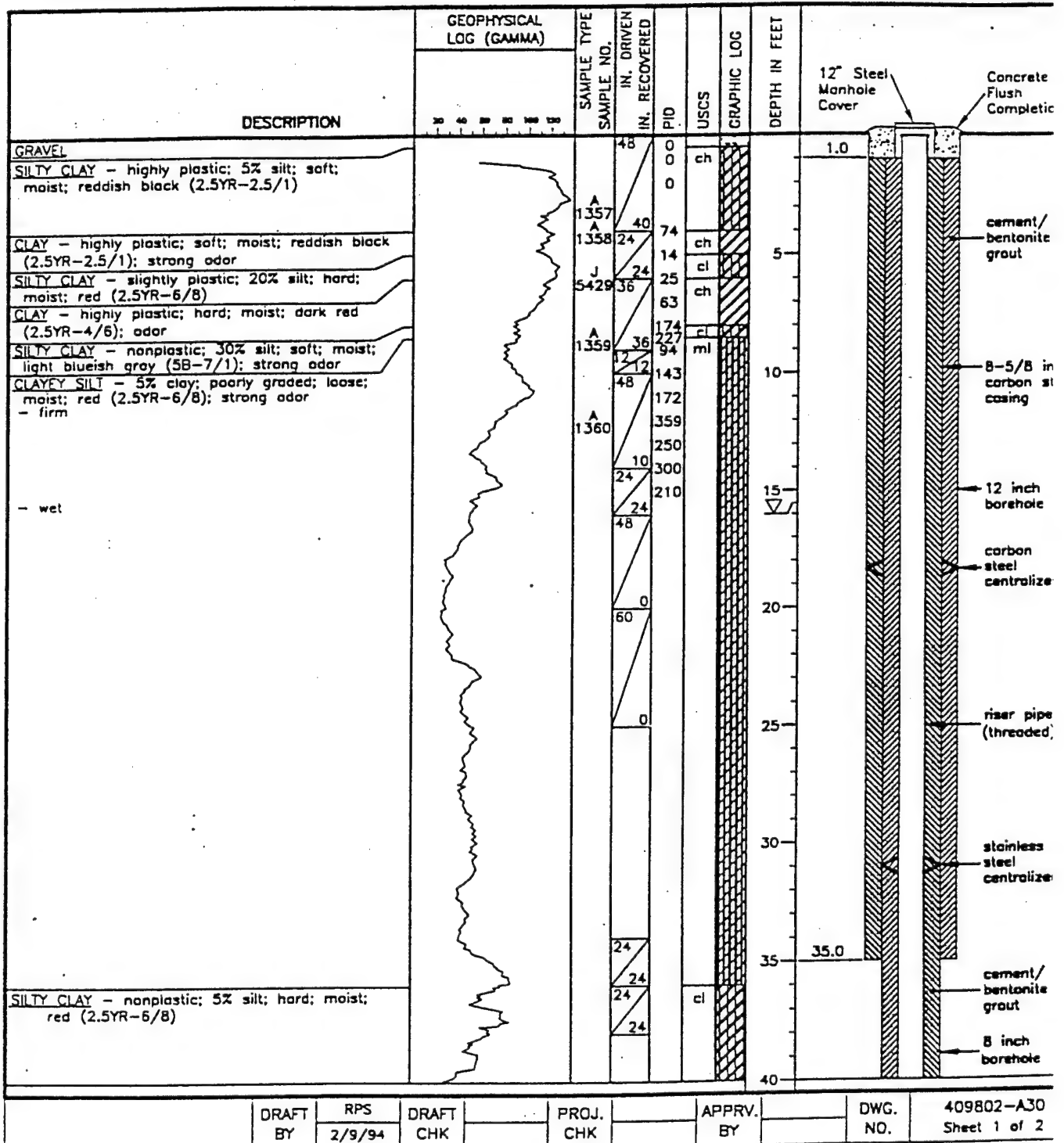
DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A
PAD ELEV.(FT): 1240.98
TOTAL DEPTH(FT.): 74.0
Logged By: P. SCHUMANN, V. CRNICH
Date Started: 11/22/93
Drilled By: J. WALKER
Date Completed: 12/29/93
GPI
Drill Rig Type: MOBILE B-61 AND TH-60
Drilling Method: HOLLOW STEM AUGER
AND MUD ROTARY
Sampling Method: 3" I.D CONTINUOUS SAMPLER

WELL COMPLETION DATA

Elev-Top of Casing(FT.): 1240.81
Ref. Datum: NGVD
1. Surf Casing-I.D.(in.): 8-5/8
Depth(FT.): 35.0
Type: Carbon
Centralizers-Type: C.Steel
Depth(FT.): 18.4
2. Riser Pipe-I.D.(in.): 2
Depth(FT.): 61.0
Type: S.Steel
Centralizers-Type: S.Steel
Depths(FT.): 31.0
Type: S.Steel Millslotted
Depth Interval(FT.): 61.0-71.0
Slot Size(in.): .010
Centralizers-Type: S.Steel
Depths(FT.): 60.4
3. Screen Dia.(in.): 2
Depth Interval(FT.): 59.0-71.5
Filter Pack Type: Silica Sand
Conc. Pad Size: 4'x4'x6"

Notes: 6" BOREHOLE
COORDINATES-NAD 27: N 158368.779, E 2180374.657



Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

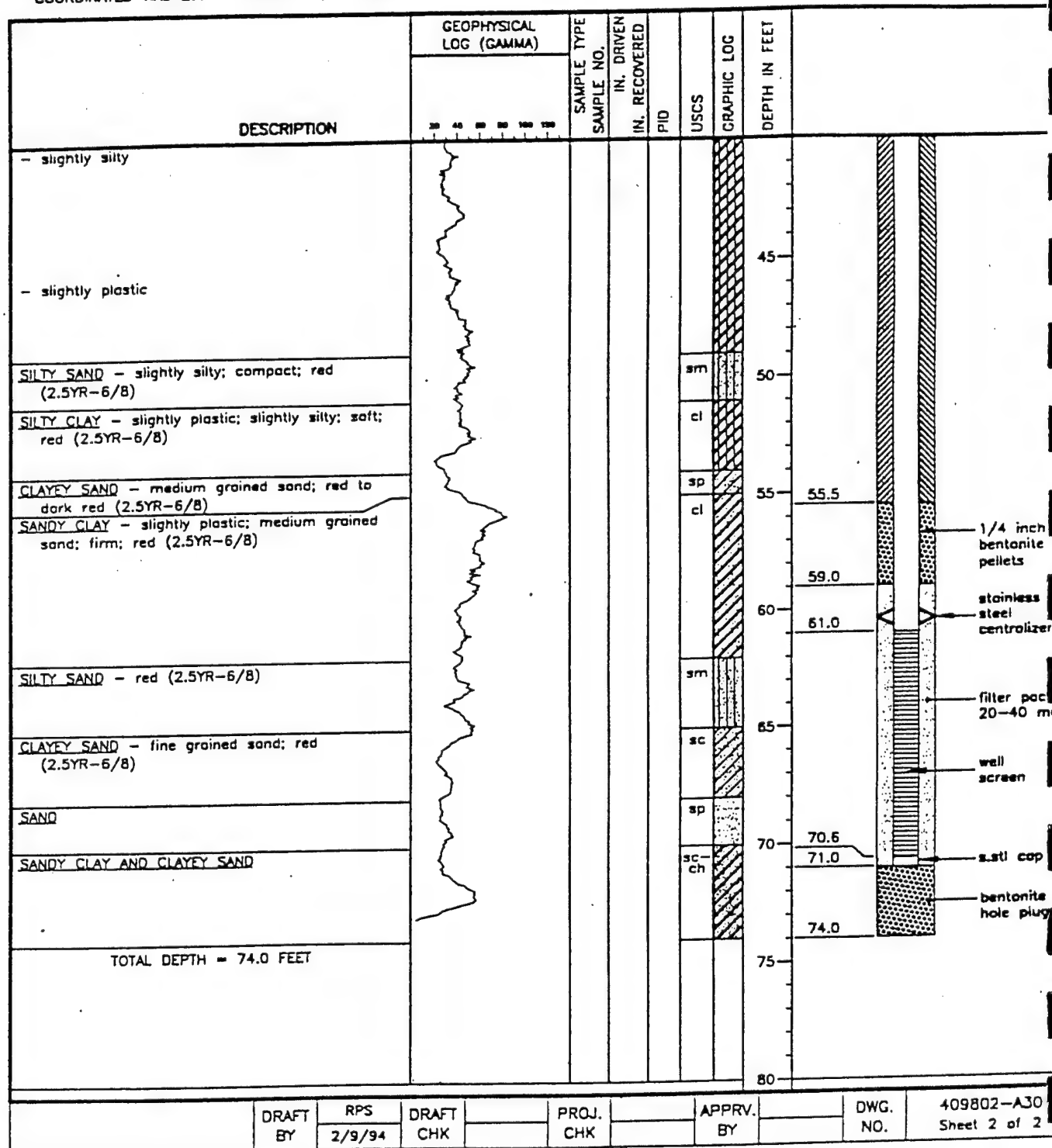
MONITORING WELL 2-

WELL COMPLETION DATA

Elev-Top of Casing(ft.): 1240.81		Ref. Datum: NGVD
1. Surf Casing-I.D.(in.): 8-5/8	Depth(ft.): 35.0	Type: Carbon
Centralizers-Type: C.Steel	Depths(ft.): 18.4	
2. Riser Pipe-I.D.(in.): 2	Depth(ft.): 61.0	Type: S.Steel
Centralizers-Type: S.Steel	Depths(ft.): 31.0	
3. Screen Dia.(in.): 2	Type: S.Steel	Millslotted
Depth Interval(ft.): 61.0-71.0	Slot Size(in.): .010	
Centralizers-Type: S.Steel	Depths(ft.): 60.4	
4. Filter Pack Type: Silica Sand	Depth Interval(ft.): 59.0-71.5	
Conc. Pod Size: 4"x4"x5"		

Drill Rig Type: MOBILE B-61 AND TH-60
Drilling Method: HOLLOW STEM AUGER
AND MUD ROTARY
Sampling Method: 5" I.D. CONTINUOUS SAMPLER

Notes: 8" BOREHOLE
COORDINATES—NAD 27: N 158368.779, E 2180374.657



Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-51

DRILLING AND SAMPLING INFORMATION

Boring Location: SOUTHEAST OF BUILDING 410
Logged By: V. CRNICH
Drilled By: J. WALKER
GPI

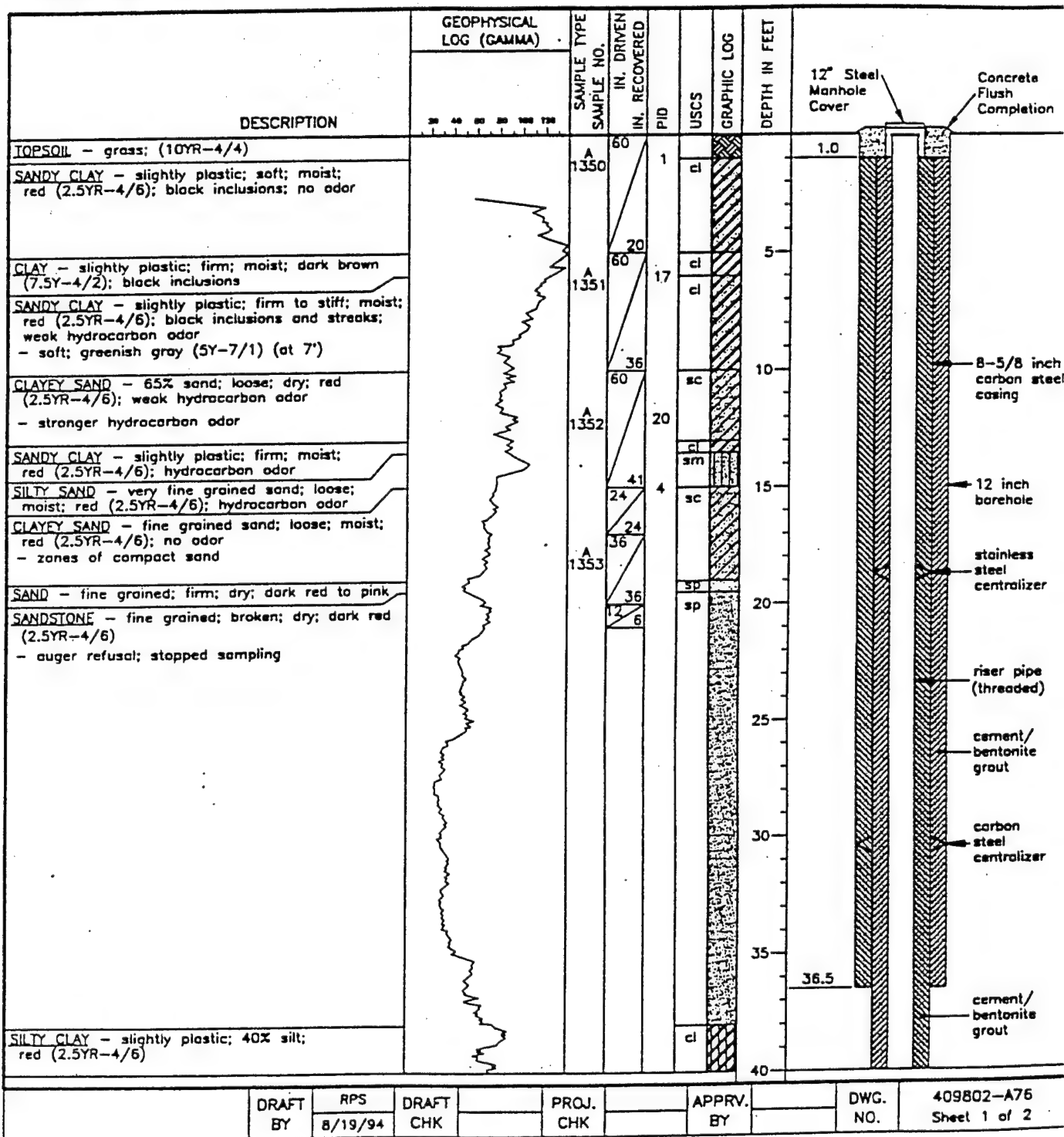
PAD ELEV.(FT): 1241.77
TOTAL DEPTH(FT.): 74.0
Date Started: 11/8/93
Date Completed: 12/27/93

Drill Rig Type: TH-60, INGERSOL RAND
Drilling Method: HOLLOW STEM AUGER AND MUD ROTARY
Sampling Method: 2"x2" CONTINUOUS SPLIT SPOON

WELL COMPLETION DATA

Elev-Top of Casing(ft.): 2141.65 Ref. Datum: NGVD
1. Surf Casing-I.D.(in.): 8-5/8 Depth(ft.): 36.5 Type: Carbon Ste
Centralizers-Type: C.Steel Depths(ft.): 18.75
2. Riser Pipe-I.D.(in.): 2 Depth(ft.): 61.6 Type: S.Steel
Centralizers-Type: S.Steel Depths(ft.): 30.4, 61.0
3. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(ft.): 61.6-71.6 Slot Size(in.): .010
Centralizers-Type: Depths(ft.):
4. Filter Pack Type: Silica Sand Depth Interval(ft.): 60.1-74.0
Conc. Pad Size: 4'x4'x6"

Notes: 8" AND 12" BOREHOLE
COORDINATES-NAD 27: N 158317.014, E 2180427.678



Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-51

DRILLING AND SAMPLING INFORMATION

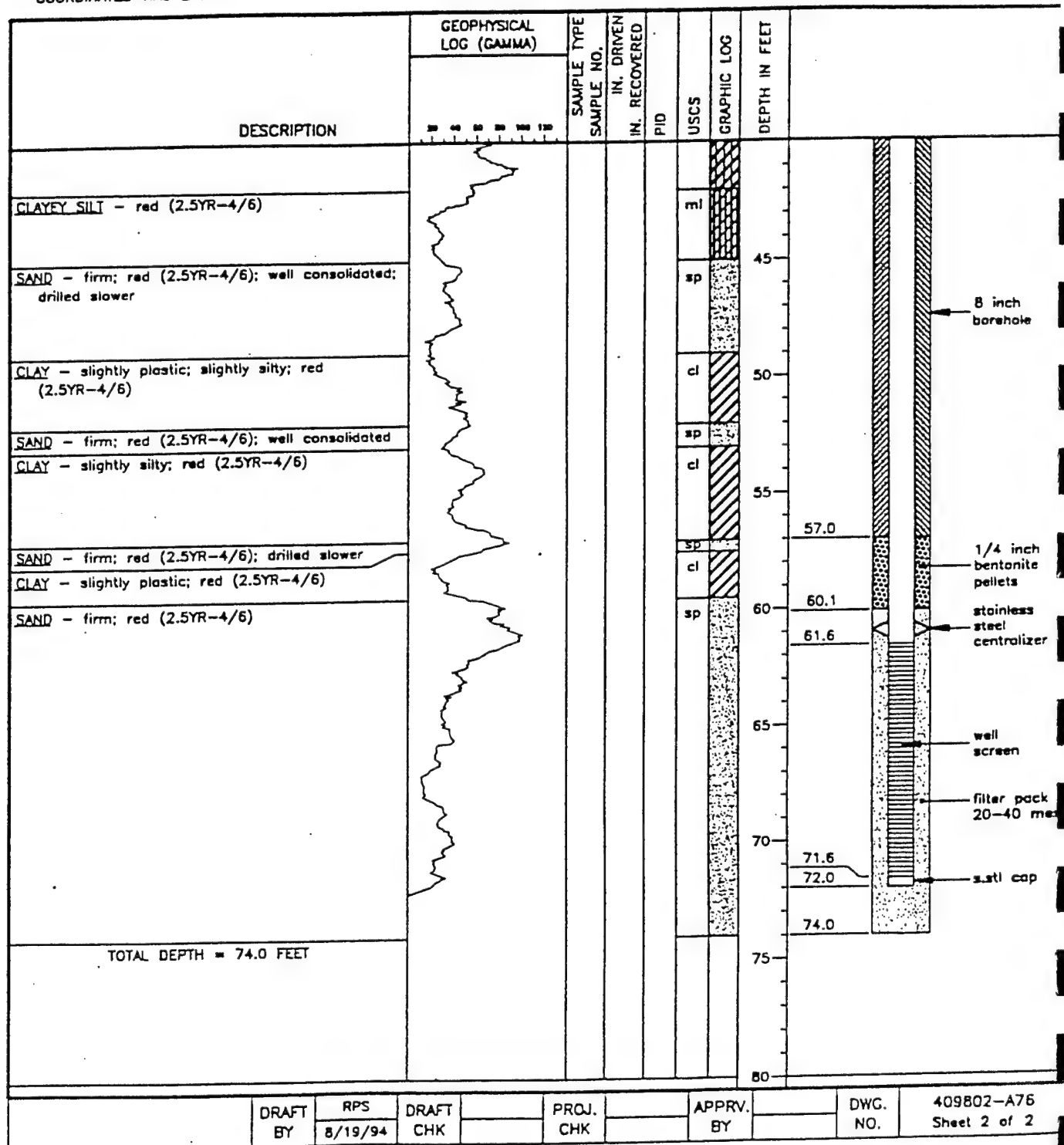
Boring Location: SOUTHEAST OF BUILDING 410
Logged By: V. CRNICH
Drilled By: J. WALKER
GPI
Drill Rig Type: TH-60, INGERSOL RAND
Drilling Method: HOLLOW STEM AUGER AND MUD ROTARY
Sampling Method: 2"x2" CONTINUOUS SPLIT SPOON

PAD ELEV.(FT): 1241.77
TOTAL DEPTH(FT.): 74.0
Date Started: 11/8/93
Date Completed: 12/27/93

WELL COMPLETION DATA

Elev-Top of Casing(FT.): 2141.55 Ref. Datum: NGVD
1. Surf Casing-LD.(in.): 8-5/8 Depth(FT.): 36.5 Type: Carbon Steel
Centralizers-Type: C.Steel Depths(FT.): 18.75
2. Riser Pipe-LD.(in.): 2 Depth(FT.): 61.6 Type: S.Steel
Centralizers-Type: S.Steel Depths(FT.): 30.4, 61.0
3. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(FT.): 61.6-71.6 Slot Size(in.): .010
Centralizers-Type: Depths(FT.):
4. Filter Pack Type: Silica Sand Depth Interval(FT.): 60.1-74.0
Conc. Pod Size: 4"x4"x6"

Notes: 8" AND 12" BOREHOLE
COORDINATES-NAD 27: N 158317.014, E 2180427.678



DRAFT BY RPS 8/19/94 DRAFT CHK

PROJ. CHK

APPRV. BY

DWG. NO.

409802-A76
Sheet 2 of 2

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-5

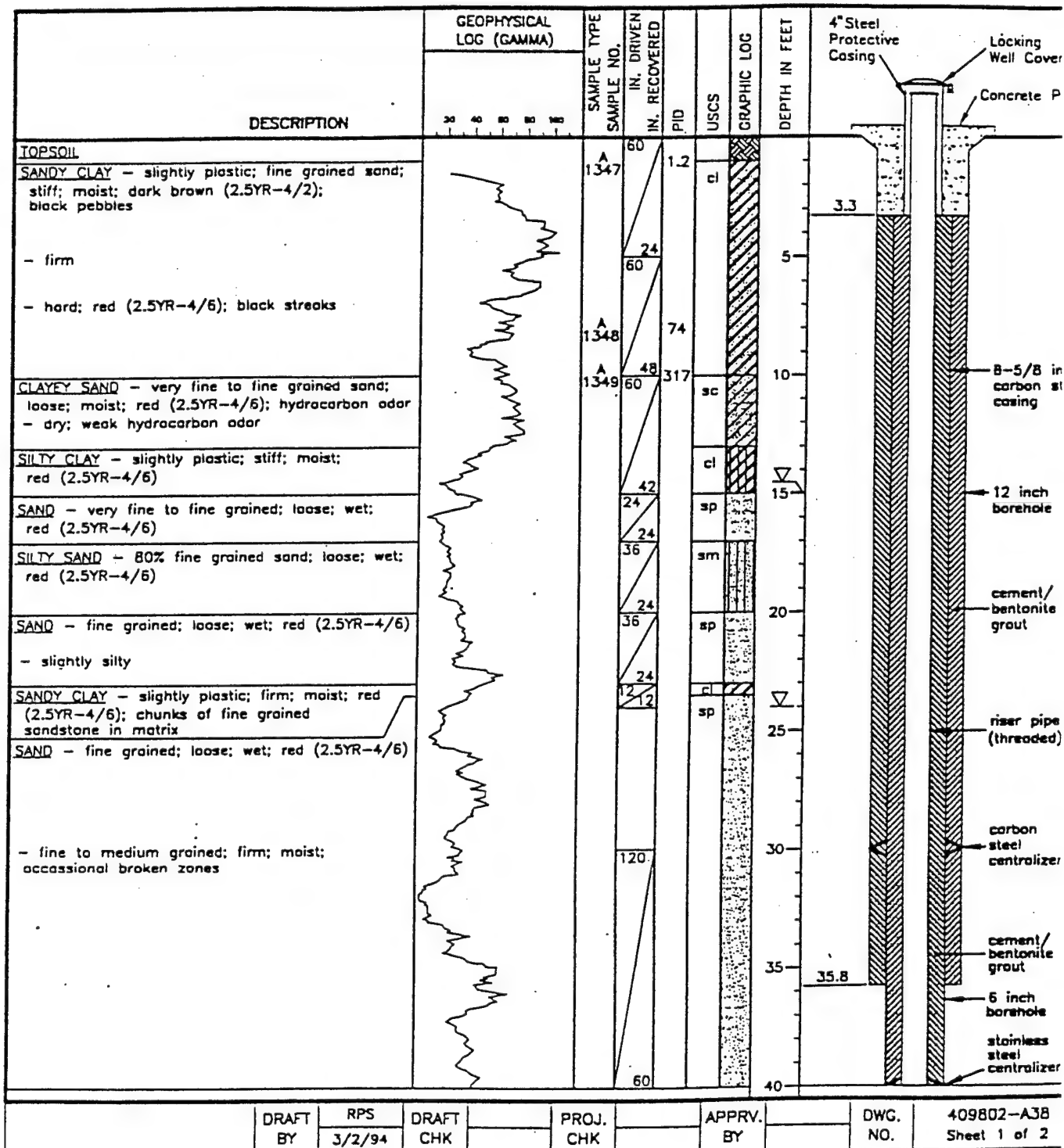
DRILLING AND SAMPLING INFORMATION

WELL COMPLETION DATA

Boring Location: AREA A	PAD ELEV.(FT):	1239.83
	TOTAL DEPTH(FT.):	72.0
Logged By: V. CRNICH	Date Started:	11/3/93
Drilled By: T. PATTERSON, D. FORSTER	Date Completed:	11/10/93
NESCO		
Drill Rig Type: SIMCO, FAILING 1250		
Drilling Method: HOLLOW STEM AUGER AND MUD ROTARY		
Sampling Method: 5'x2.5" CONTINUOUS SAMPLER		

Elev-Top of Casing(ft.): 1241.98		Ref. Datum: NGVD
1. Surf Casing-LD(in.): 8-5/8	Depth(ft.): 35.8	Type: Carbon
Centralizers-Type: S.Steel	Depths(ft.): 30.0	
2. Riser Pipe-LD(in.): 2	Depth(ft.): 56.8	Type: S.Steel
Centralizers-Type: S.Steel	Depths(ft.): 40.0	
3. Screen Dia.(in.): 2	Type: S.Steel Millslotted	
Depth Interval(ft.): 56.8-66.5	Slot Size(in.): .010	
Centralizers-Type: S.Steel	Depths(ft.): 60.4	
4. Filter Pack Type: Silica Sand	Depth Interval(ft.): 55.0-66.8	
Conc. Pad Size: 4'x4'x5'		

Notes: 6-1/4" BOREHOLE AND 12" BOREHOLE
COORDINATES--NAD 27: N 158283.581, E 2180247.928



Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-5

DRILLING AND SAMPLING INFORMATION

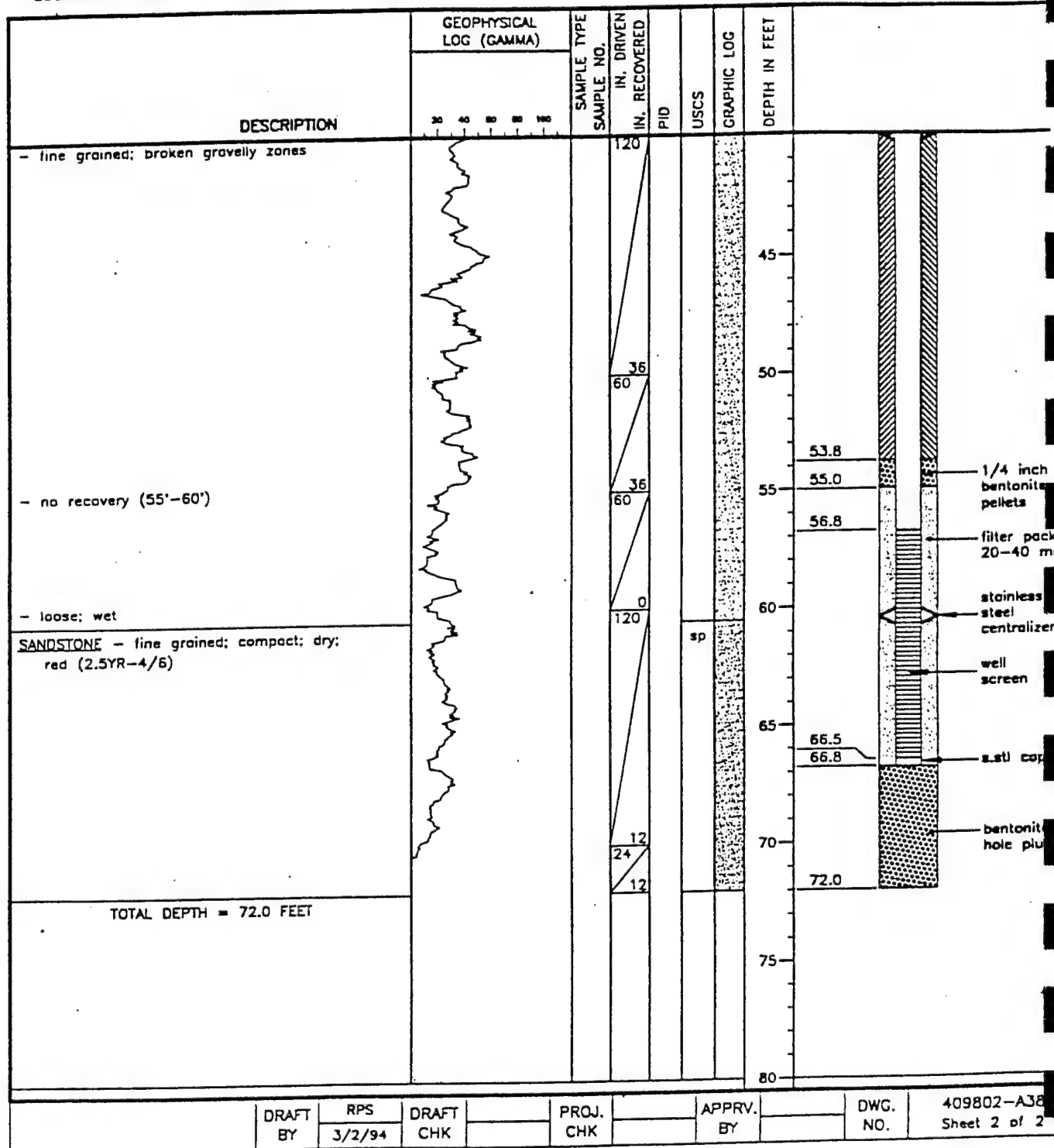
Boring Location: AREA A
Logged By: V. CRNICH
Drilled By: T. PATTERSON, D. FORSTER
Drill Rig Type: SIMCO, FAILING 1250
Drilling Method: HOLLOW STEM AUGER AND MUD ROTARY
Sampling Method: 5'x2.5" CONTINUOUS SAMPLER

PAD ELEV.(FT): 1239.83
TOTAL DEPTH(FT.): 72.0
Date Started: 11/3/93
Date Completed: 11/10/93

WELL COMPLETION DATA

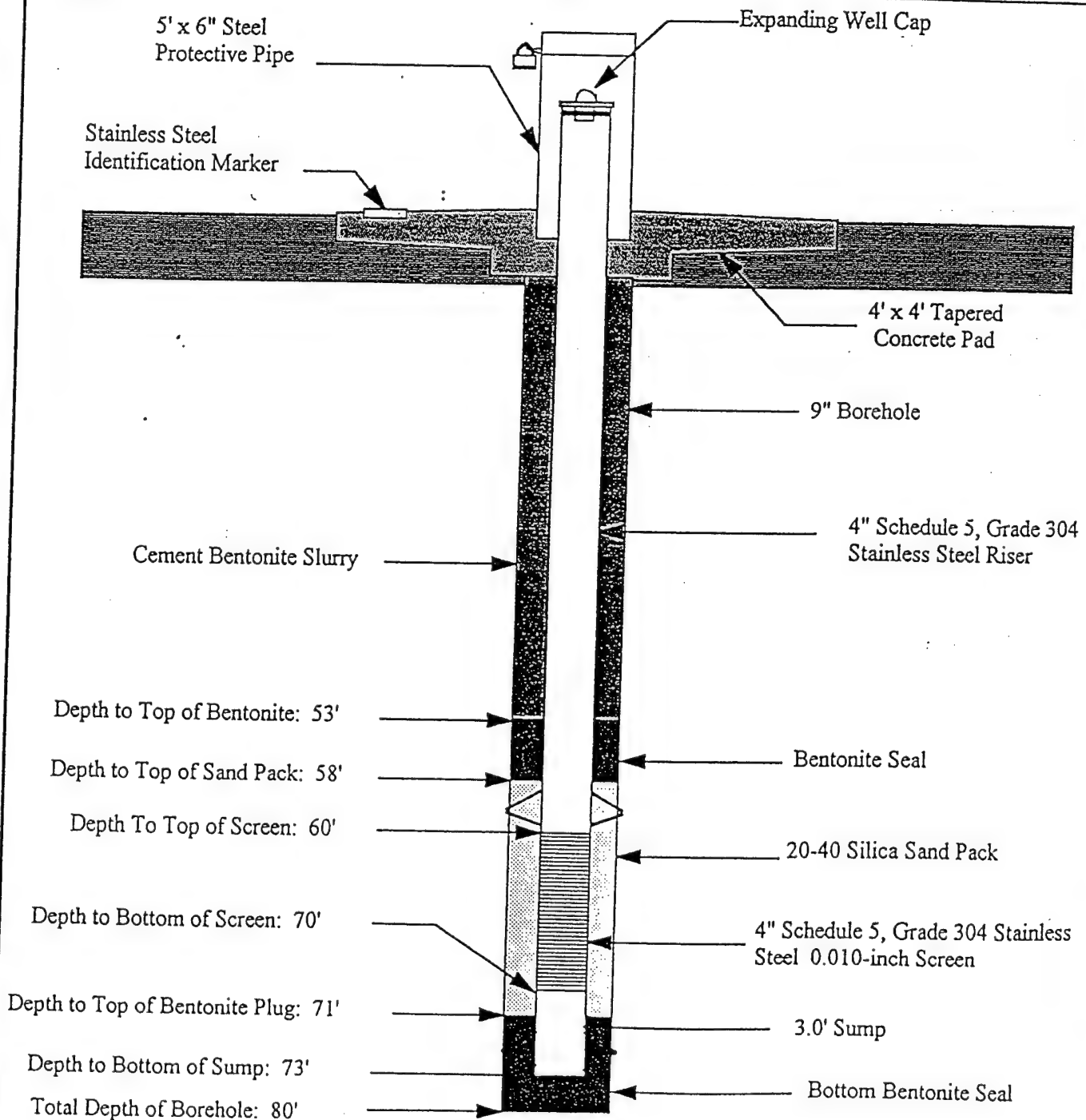
Elev-Top of Casing(FT.): 1241.98 Ref: Datum: NGVD
1. Surf Casing-LD.(in.): 8-5/8 Depth(FT.): 35.8 Type: Carbon Steel
Centralizers-Type: S.Steel Depths(FT.): 30.0
2. River Pipe-LD.(in.): 2 Depth(FT.): 56.8 Type: S.Steel
Centralizers-Type: S.Steel Depths(FT.): 40.0
3. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(FT.): 56.8-66.5 Slot Size(in.): .010
Centralizers-Type: S.Steel Depths(FT.): 60.4
4. Filter Pack Type: Silica Sand Depth Interval(FT.): 55.0-66.8
Conc. Pad Size: 4'x4'x6"

Notes: 6-1/4" BOREHOLE AND 12" BOREHOLE
COORDINATES-NAD 27: N 158283.581, E 2180247.928



WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-147A
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 02/01/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1268.58'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1271.51'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Riser Casing.	

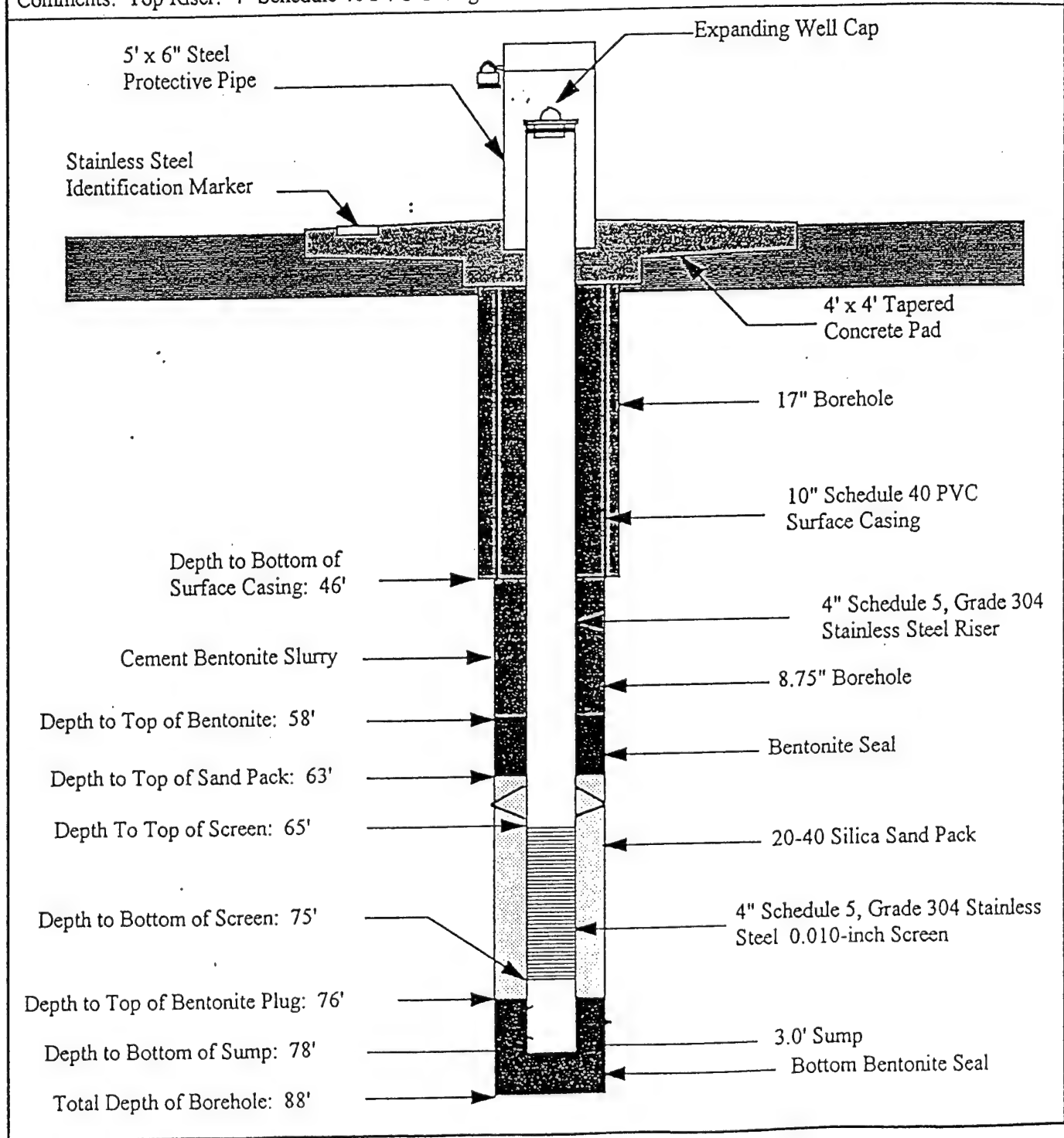


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-148A
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/11/95
Contractor: Brown & Root Environmental	Drilling Method: Auger, 0'-46'; Mud Rotary, 46'-88'
Project Manager: David Parker	Ground Level Elev. (AMSL): 1247.45'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1250.11'
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	

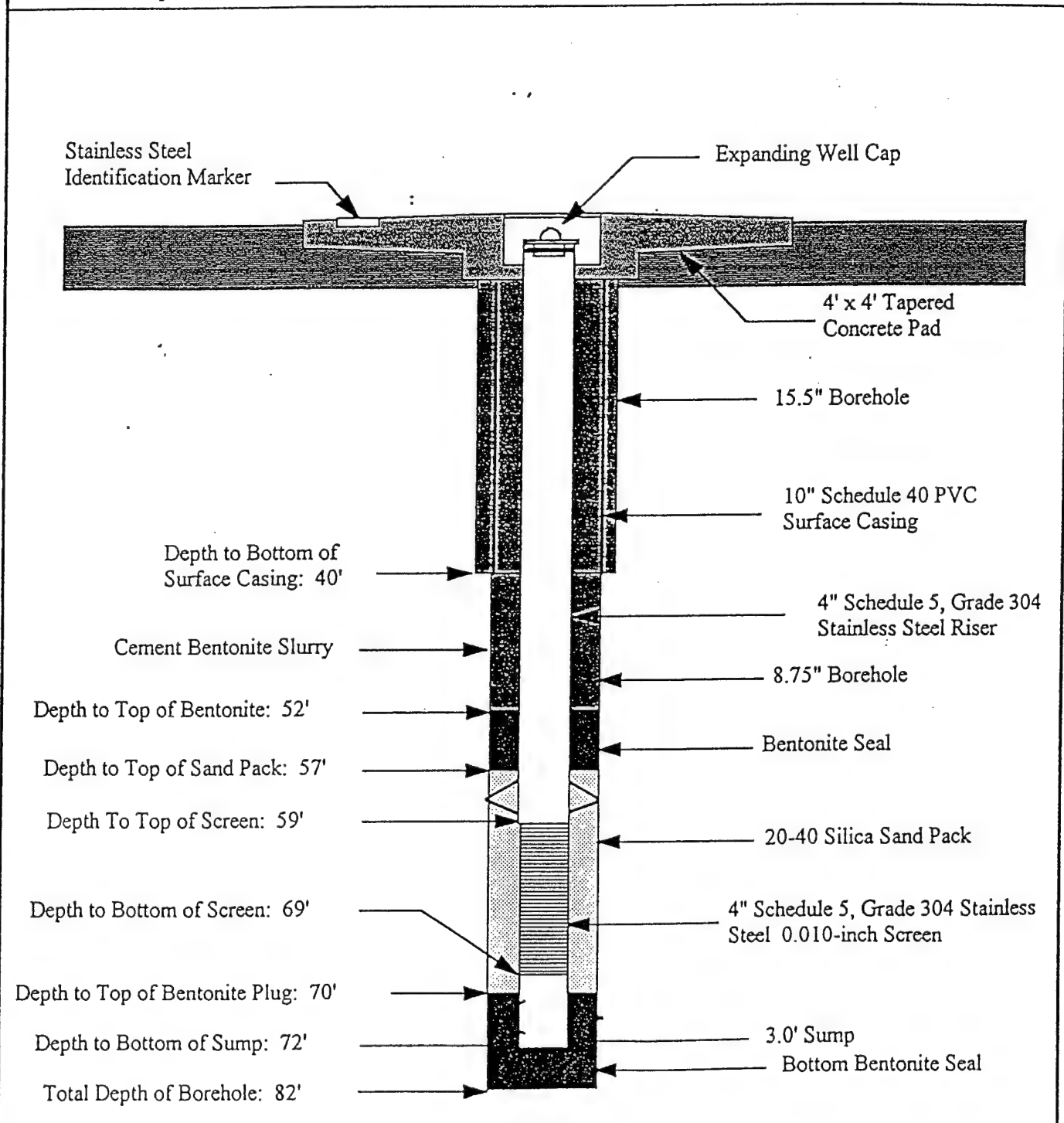


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-149A
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/05/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1237.39'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1236.72'
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	

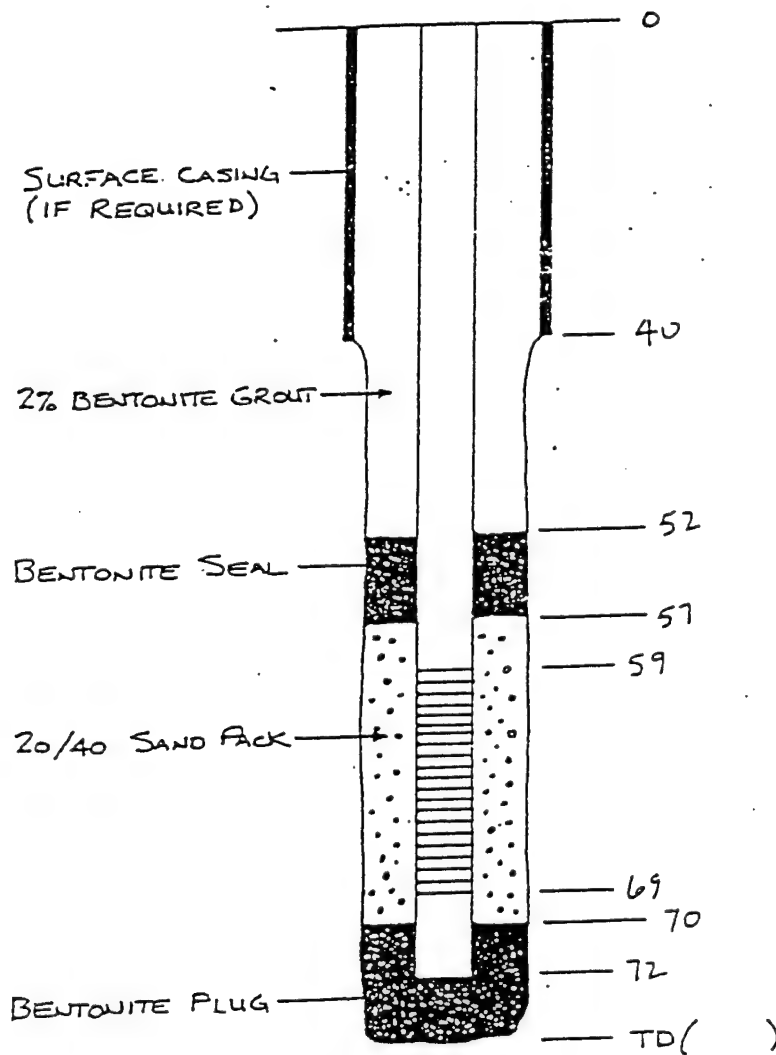


Drawing not to scale

< > Centralizers

~

Well ID	Recommended Construction		Comments
	Item	Depth	
2-149A	Surface Casing	0-40	
	Inner Casing	-	
	Grout	0-52	
	Bentonite Seal (top)	52-57	
	Sand Pack	57-70	
	Bentonite Seal (bottom)	70-72	
	Riser	0-59	
	Screen	59-69	
	Sump	69-72	



Log Received
6-5-75 12:10

1 LOG RUN

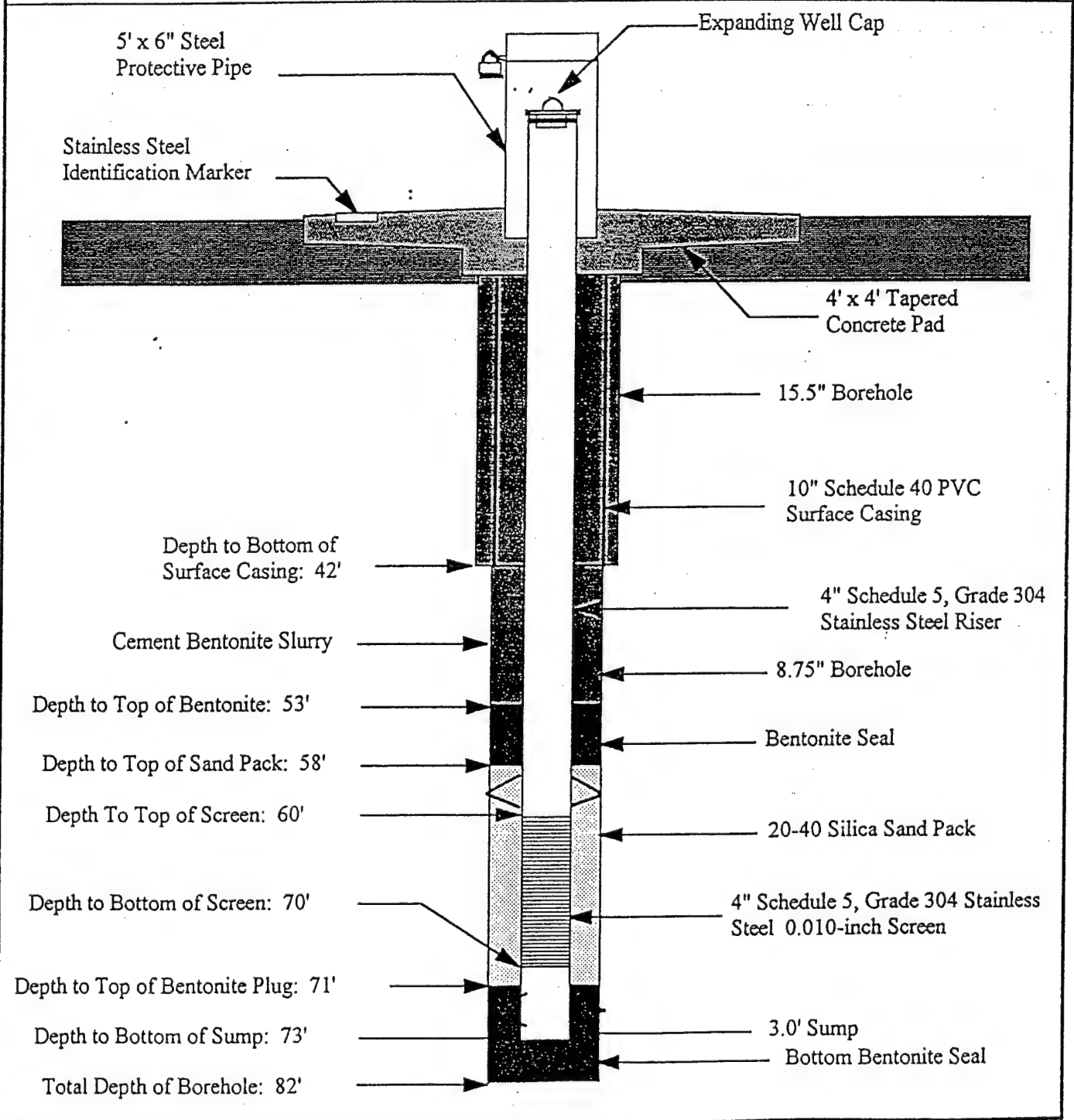
2 LOG RUN

Well Design Delivered

6-5-75 12:10

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-150A
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/17/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1231.28'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1233.80'
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	

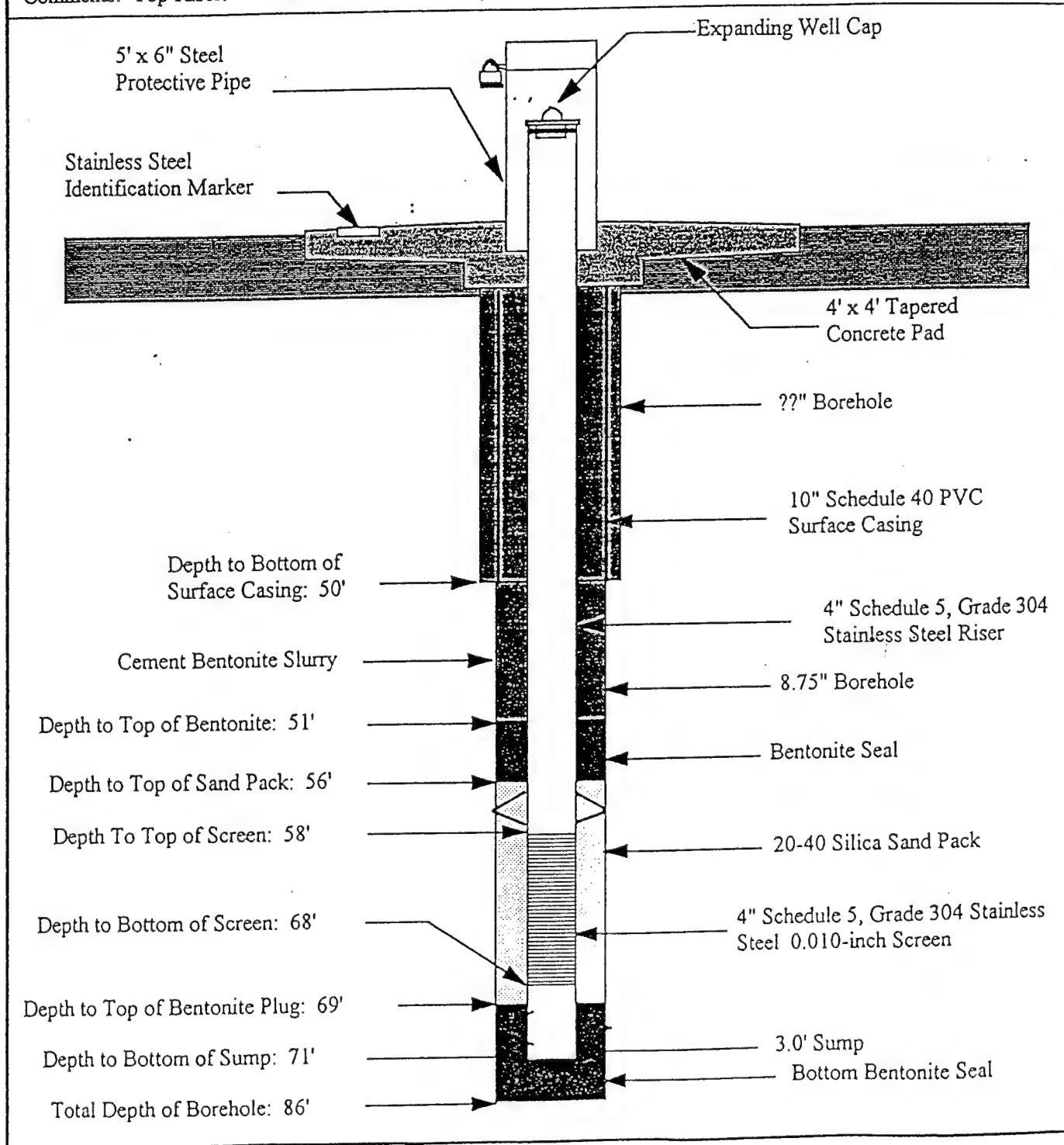


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-152A
Location: TAFB, Oklahoma	Site: BW
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/18/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1243.63'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1246.36'
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	



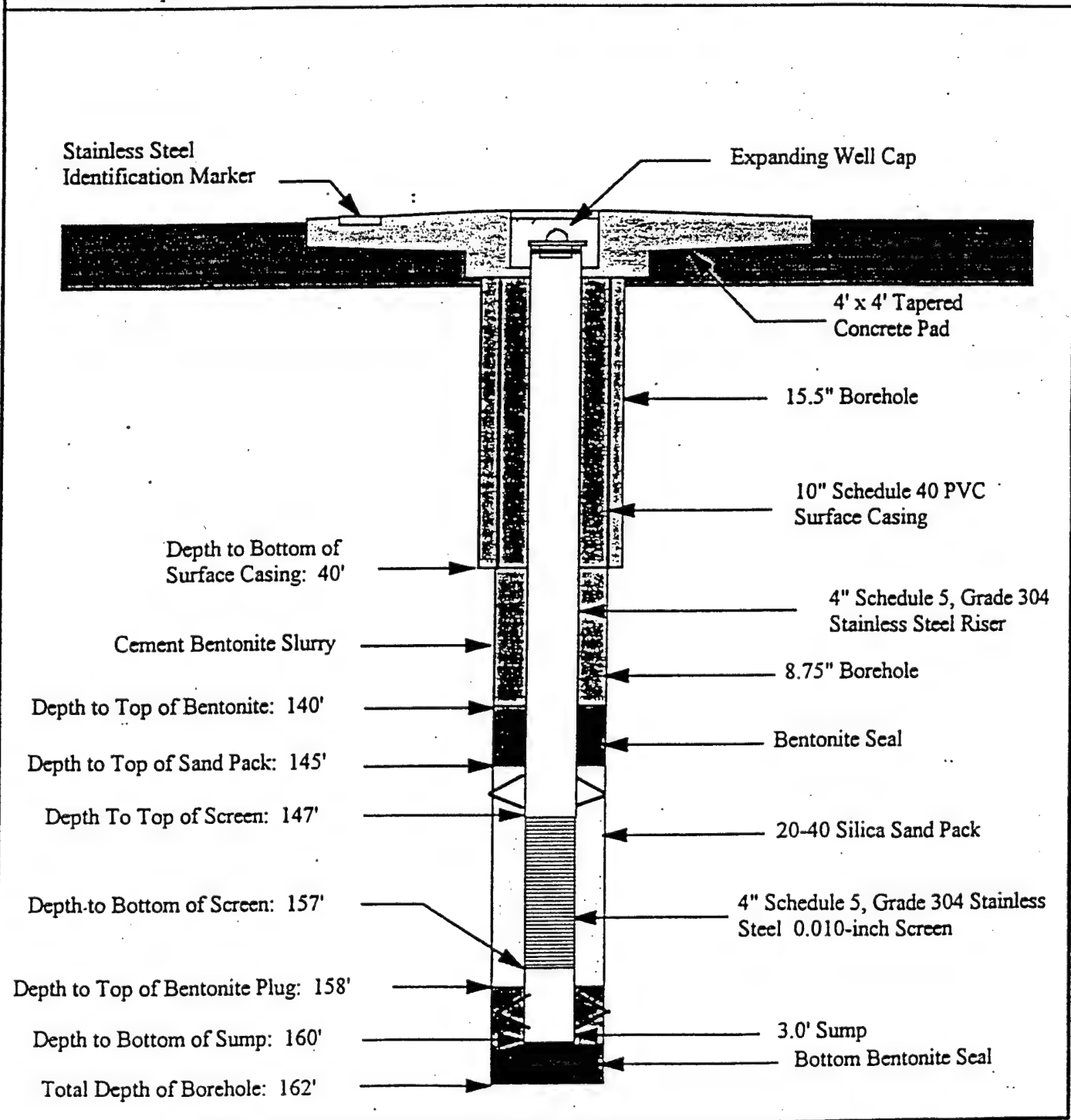
Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

(2)

Client: Tinker Air Force Base	Well ID: 2-149C
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/06/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): '
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): '
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing	

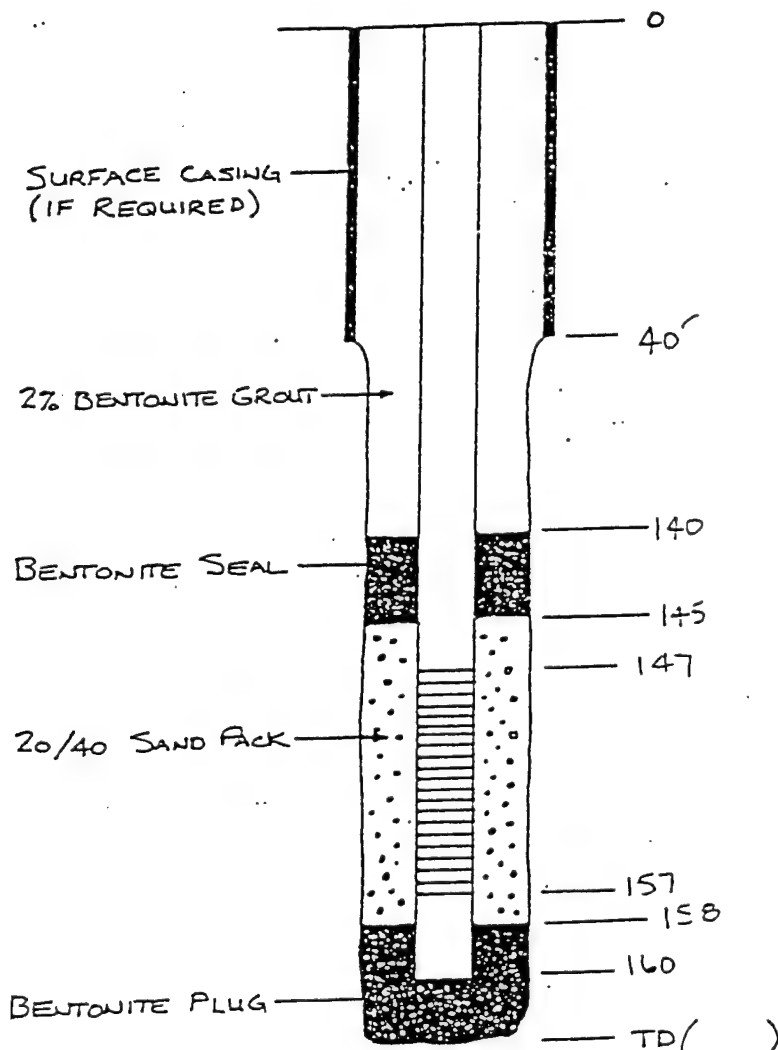


Drawing not to scale

< > Centralizers

N

Well ID	Recommended Construction		Comments
	Item	Depth	
2-149C	Surface Casing	0-40'	
	Inner Casing	—	
	Grout	0-140	
	Bentonite Seal (top)	140-145	
	Sand Pack	145-158	
	Bentonite Seal (bottom)	158-TD	
	Riser	0-147	
	Screen	147-157	
	Sump	157-160	



Log Received
6-5-95 5:30

1 LOG RUN

2 LOG RUN

well Design Delivery
6-5-95 5:40

Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

SOIL BORING SB-0

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A

SURFACE ELEV.(FT): 1241.24 NGVD

TOTAL DEPTH(FT.): 25

Logged By: P. SCHUMANN, K. HERRINGTON

Date Started: 10/21/93

Drilled By: D. EYLER

Date Completed: 10/22/93

NESCO

Drill Rig Type: RODGERS 760

Drilling Method: HOLLOW STEM AUGER

Sampling Method: 5" I.D. CONTINUOUS SAMPLER

Notes: 8" DIAMETER BOREHOLE

COORDINATES-NAD 27: N 158461.461, E 2180256.673

DESCRIPTION	SAMPLE TYPE SAMPLE NO.	IN. DRIVEN IN. RECOVERED	FID	USCS	GRAPHIC LOG
<u>CLAY</u> - moderately plastic; firm; dark reddish brown (5YR-3/3); dry - hard; (5YR-3/2)	A 1167	60	0	ch	
- reddish brown (5YR-4/6)		60	0		
- occasional pebbles; dark red (2.5YR-4/6)		60	0		
		60	0		
		60	0		
<u>SILTY CLAY</u> - nonplastic; 50% silt; stiff; light blueish gray (5B-7/1); dry	A 1168	60	0	cl	
<u>CLAY</u> - moderately plastic; hard; occasional pebbles; silty light blueish gray layers; dark red (2.5YR-4/6); dry - stiff; red (2.5YR-5/8)		60	0	ch	
<u>SILTY CLAY</u> - nonplastic; 20% silt; firm; 3" discolored layer; gray (N6); strong gasoline odor	A 1170	5	0	cl	
<u>CLAY</u> - moderately plastic; firm; occasional pebbles; red (2.5YR-5/8); dry		0	0	ch	
<u>SILTY CLAY</u> - nonplastic; 20% silt; soft; red (10R-4/8); dry	A 1171	60	0	cl	
<u>CLAY</u> - moderately plastic; hard; increasing fines; gray silty layers; red (10R-4/8); moist; on odor		6	0	cl	
<u>SAND</u> - very fine grained; poorly graded; loose; increasing clay content with depth; light gray to reddish yellow (5YR-6/6); moist to wet - 10% to 20% clay; moderately graded; reddish yellow (5YR-6/6); no odor	A 1172	0	0	ml	
<u>CLAY</u> - slightly plastic; hard; reddish brown (5YR-4/4); dry		60	0	ch	
<u>SILTY CLAY</u> - slightly plastic; 20% silt; soft; red (2.5YR-5/8); wet; on odor		0	0	ch	
<u>CLAY</u> - plastic; soft; red (2.5YR-5/8); moist; on odor		0	0	sc	
<u>SAND</u> - very fine grained; 10% fines; moderately graded; loose; red (2.5YR-5/8); moist to wet; compact at 23'		48	0		
TOTAL DEPTH = 25.0 FEET					

DRAFT BY	RPS 11/15/93	DRAFT CHK	PROJ. CHK	APPRV. BY	DWG. NO.	409802-A20 Sheet 1 of 1
----------	-----------------	--------------	--------------	--------------	-------------	----------------------------

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

SOIL BORING SB-01

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A

SURFACE ELEV.(FT): 1240.78 NGVD

TOTAL DEPTH(FT.): 20

Logged By: P. SCHUMANN, K. HERRINGTON

Date Started: 10/25/93

Drilled By: D. EYLER

Date Completed: 10/25/93

NESCO

Drill Rig Type: RODGERS 760

Drilling Method: HOLLOW STEM AUGER

Sampling Method: 5" I.D. CONTINUOUS SAMPLER

Notes: 8" DIAMETER BOREHOLE

COORDINATES--NAD 27: N 158291.785, E 2180348.712

COORDINATES - NAD 27: N 102°58'00" E 100' 0" S							SAMPLE TYPE	SAMPLE NO.	IN. DRIVEN	IN. RECOVERED	FID	USCS	GRAPHIC LOG
DESCRIPTION													
<u>SILTY CLAY</u> - slightly plastic; 20% silt; soft; small gravel layer at 1'; strong brown (2.5YR-4/6); dry - highly plastic; hard; yellowish red (5YR-4/6); moist - moderately plastic; firm; dark olive brown (2.5Y-3/3)													
<u>CLAY</u> - highly plastic; hard; dark olive brown (2.5Y-3/3); moist - stiff; olive brown streaks; yellowish red (5YR-5/6) - hard - some 1" greenish gray layers; strong odor - firm; dark red (2.5YR-4/8)													
<u>SAND</u> - very fine grained; 20% fines; moderately graded; compact; some grayish green streaking; reddish yellow (5YR-6/8); moist; gasoline odor - 10% fines; poorly graded; loose; saturated with product (gasoline) - 15% fines; moderately graded; yellowish red (5YR-5/8); wet; slight product odor - sample lost during removal													
TOTAL DEPTH = 20.0 FEET													
DRAFT BY	RPS 11/16/93	DRAFT CHK	PROJ. CHK	APPRV. BY	DWG. NO.	409802-A2 Sheet 1 of							

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

SOIL BORING SB-01

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A

SURFACE ELEV.(FT): 1240.43 NGVD

TOTAL DEPTH(FT.): 18

Logged By: P. SCHUMANN, K. HERRINGTON

Date Started: 10/25/93

Drilled By: D. EYLER

Date Completed: 10/26/93

NESCO

Drill Rig Type: RODGERS 760

Drilling Method: HOLLOW STEM AUGER

Sampling Method: 5" I.D. CONTINUOUS SAMPLER

Notes: 8" DIAMETER BOREHOLE

COORDINATES-NAD 27: N 158257.819, E 2180317.691

DESCRIPTION										SAMPLE TYPE	SAMPLE NO.	IN. DRIVEN	IN. RECOVERED	FID	USCS	GRAPHIC LOG
CLAYEY SILT - 30% clay; organics; moderately graded; loose; dark yellowish brown grading to yellowish red (10YR-4/4); dry										A	1177	60	0	0	ol	
SILTY CLAY - moderately plastic; 10% silt; stiff; brown (7.5YR-4/4); dry												0	0	0	ch	
SAND - very fine to medium grained; moderately graded; loose; red (2.5YR-5/8); moist - wet												0	0	0	sp	
SILTY GRAVELLY CLAY - highly plastic; 10% silt, 10% gravel; soft; dark gray (N4) streaking; red (2.5YR-5/8); moist - stiff - slightly plastic; 5% silt, 5% gravel; soft; red (2.5YR-6/8); dry; strong product odor										A	1178	48	200	200	ch	
SILTY CLAY - moderately plastic; 20% silt; soft; red (2.5YR-5/8); moist; strong product odor										A	1179	60	4000	4000	cl	
SILTY GRAVELLY CLAY - slightly plastic; 5% silt, 5% gravel; hard; dark gray streaks; red (2.5YR-5/8); dry; strong product odor										A	1180	36	20	20	cl	
SAND - very fine grained; poorly graded; compact; red (2.5YR-5/8); moist												60	50	50	sp	
SILTY CLAY - nonplastic; 10% silt; soft; red (2.5YR-5/8); moist; strong product odor												36	20	20	cl	
SAND - very fine grained; poorly graded; loose; red (2.5YR-5/8); moist - very fine to fine grained; wet												36	10	10	sp	
TOTAL DEPTH - 18.0 FEET																

DRAFT
BY

RPS
11/16/93

DRAFT
CHK

PROJ.
CHK

APPRV.
BY

DWG.
NO.

409802-A2
Sheet 1 of

Table 5-1
Upper Saturated Zone
Monitoring Well Water Levels
Area A Service Station

Well Number	Top of Casing Elevation (ft. NGVD)	Date Measured	Static Depth of Groundwater (ft. btoc)	Elevation of Water Level (ft. NGVD)	Measured Depth of HC (ft. btoc)	Thickness of HC
2-50B	1241.30	1/31/94	15.02	1226.28		
		2/6/94	14.83	1226.47	14.82	0.01
		9/6/94	16.82	1226.19	16.82	1.97
		11/2/94	15.12	1226.18	14.85	0.27
		7/14/95	15.30	1226.00		
2-51B	1241.29	2/6/94	11.09	1230.20		
		9/6/94	10.92	1230.37		
		11/2/94	11.32	1229.97		
		1/9/95	11.55	1229.74		
		7/14/95	10.15	1231.14		
2-52B	1241.81	2/6/94	14.11	1227.70		
		9/6/94	14.79	1227.02		
		11/2/94	14.45	1227.36		
		1/9/95	15.02	1226.79		
		7/14/95	14.15	1227.66		
2-2	1242.27	1/9/94	14.00	1228.27		
		9/6/94	15.63	1226.64		
2-2	1241.99	11/2/94	15.33	1226.94		
		1/9/95	15.38	1226.89		
		7/14/95	15.34	1226.65		
2-3	1242.38	1/19/94	15.75	1226.63		
		9/6/94	16.41	1225.97		
2-3	1242.34	11/3/94	16.26	1226.08		
		1/9/95	16.38	1225.96		
		7/14/95	15.79	1226.55		
2-4	1243.16	1/18/94	19.60	1223.56		
		9/6/94	20.89	1226.04	16.55	4.34
		11/2/94	17.54	1225.62	16.73	0.81
		1/9/95	20.71	1222.45		
		7/14/95	19.3	1223.86		
2-145B	1242.75	7/13/95	10.09	1232.66		
2-146B	1240.70	7/11/95	10.29	1230.41		
2-149B	1236.55	7/11/95	18.20	1218.35		
2-163B	1237.10	7/14/95	13.25	1223.85		
2-164B	1238.94	7/14/95	13.47	1225.47		

Table 5-1 (continued)
Upper Saturated Zone
Monitoring Well Water Levels
Area A Service Station

Well Number	Top of Casing Elevation (ft. NGVD)	Date Measured	Static Depth of Groundwater (ft. btoc)	Elevation of Water Level (ft. NGVD)	Measured Depth of HC (ft. btoc)	Thickness of HC
2-165B	1223.60	7/14/95	5.07	1218.53		
2-166B	1244.97	7/14/95	17.96	1227.01		

Where free-phase hydrocarbon is present, the water level has been corrected using the formula:

$$C = (SG \times T) + M$$

Where: C = corrected water level
SG = specific gravity of hydrocarbon, assume = 0.87
T = hydrocarbon thickness
M = measured water level

Table 5-4
Lower Saturated Zone
Monitoring Well Water Levels
Area A Service Station

Well Number	Top of Casing Elevation (ft. NGVD)	Date Measured	Static Depth of Groundwater (ft. btoc)	Elevation of Water Level (ft. NGVD)
2-2A	1242.96	1/31/94	45.56	1197.40
		2/6/94	45.05	1197.91
		9/6/94	46.35	1196.61
		11/2/94	45.15	1196.81
		1/9/95	46.56	1196.40
		7/14/95	46.19	1196.77
2-4A	1240.81	1/31/94	43.17	1197.64
		2/6/94	42.65	1198.16
		9/6/94	43.93	1196.88
		11/2/94	43.69	1197.12
		1/9/95	44.13	1196.68
		7/14/95	43.74	1197.07
2-51A	1241.65	1/31/94	43.91	1197.74
		2/6/94	44.40	1197.25
		9/6/94	44.52	1197.13
		11/2/94	44.44	1197.21
		1/9/95	44.74	1196.91
		7/14/95	44.33	1197.32
2-52A	1241.98	1/31/94	44.78	1197.20
		2/6/94	44.28	1197.70
		9/6/94	45.56	1196.42
		11/2/94	45.36	1196.62
		1/9/95	45.72	1196.26
		7/14/95	45.40	1196.58
2-149A	1236.72	7/11/95	41.27	1195.45

Table 5-2
Slug Test Results
Area A Service Station

Upper Saturated Zone

		Cooper et al.				Bouwer&Rice		
Well No.	Thickness (ft)	T (ft ² /min)	K(cm/sec)	K(ft/min)	K(ft/day)	K(cm/sec)	K(ft/min)	K(ft/day)
2-50B		Method not applicable				1.3E-03	0.0025	3.6
2-51B		Method not applicable				1.4E-05	0.000028	0.04
2-52B		Method not applicable				1.9E-04	0.00038	0.55
Average Value		Method not applicable				4.9E-04	0.00097	1.4

Lower Saturated Zone

Well No.	Thickness (ft)	Cooper et al.				Bouwer&Rice		
		T (ft ² /min)	K(cm/sec)	K(ft/min)	K(ft/day)	K(cm/sec)	K(ft/min)	K(ft/day)
2-2A	12.5	0.0069	2.8E-04	0.00055	0.79	1.9E-04	0.00037	0.53
2-4A	8	0.065	4.1E-03	0.0081	11	7.0E-04	0.0014	2.0
2-51A(slug in)	17	0.097	2.9E-03	0.0057	8.2	6.9E-04	0.0014	1.9
2-51A(slug out)	16.5	0.064	2.0E-03	0.0038	5.5	6.7E-04	0.0013	1.9
2-52A(slug in)	24.3	0.069	1.4E-03	0.0028	4.0	5.3E-04	0.0010	1.5
2-52A(slug out)	16	0.022	6.9E-04	0.0013	1.9	5.1E-04	0.0010	1.4
Average Value		5.4E-02	1.9E-03	3.7E-03	5.3E+00	5.5E-04	1.1E-03	1.6E+00

Analysis performed with AQTESOLV software

T - Transmissivity (based on Cooper et al methodology for confined aquifers)

K - Hydraulic Conductivity (based on Bouwer-Rice and Cooper et al.)

ft - feet; cm - centimeters; sec - seconds; min - minutes

Table 5-7
 Analytical Results for Soil Samples
 Borings 1-S1 Thru 1-S5
 Area A Service Station

OCC Category II Cleanup Standards	Benzene (ug/kg)	Toluene (ug/kg)	Ethylbenzene (ug/kg)	Xylenes (ug/kg)	Total BTEX ¹ (ug/kg)	TPH (mg/kg)	Total Lead (mg/kg)
Sample Depth (Feet)							
1-S1	5,000	400,000	150,000	1,000,000	1,555,000	500	26 ³
1-S2	950,000 1,000,000	1,600,000 1,700,000	500,000 300,000	1,300,000 950,000	4,350,000 3,950,000	6,300 11,000	<.002 148
1-S3	<2 5,600 1,000,000	<2 61,000 2,000,000	<2 19,000 510,000	<2 110,000 1,600,000	<8 195,600 5,110,000	<10 500 8,000	22.8 10.5 10.4
1-S4	1,000,000 59,000 300,000 1,200,000	1,600,000 380,000 1,700,000 2,300,000	430,000 77,000 430,000 570,000	1,200,000 460,000 2,400,000 1,900,000	4,230,000 976,000 4,830,000 5,970,000	12,000 9,600 85,000 86,000	8.99 8.7 9.77 19.4
1-S5	<50 13,000	1,700 61,000	1,100 17,000	8,500 110,000	11,350 201,000	160 860	12.1 9.1

Source: ERI, 1990.

Samples Collected May 23-30, 1990

Shaded results indicate exceedance of OCC Cleanup Standards or Background

BTEX - (Benzene, Toluene, Ethylbenzene, Xylenes) by Method 8020

TPH - Total Petroleum Hydrocarbons by Method 418.1

Total Lead By Method 6010

¹Total BTEX computed by summation of BTEX compounds

²Background concentration (IT, 1995b)

Table 5-8
Analytical Results for Soil Samples
Borings SB-1 Thru SB-8
Area A Service Station

		Benzene (ug/kg)	Toluene (ug/kg)	EthylBenzene (ug/kg)	Xylenes (ug/kg)	Total BTEX ¹ (ug/kg)	TPH (mg/kg)	Total Lead (mg/kg)
OCC Category II Cleanup Standards		5,000	400,000	150,000	1,000,000	1,555,000	500	26 ²
Boring Number	Sample Depth (Feet)							
SB-1	12-15	26,400	140,000	63,300	247,000	476,700	6170	13.5(.7*)
	15-17	12,300	109,000	53,800	215,000	390,100	3140	7.6(.4*)
	19	ND	322	187	1080	1,589	ND	ND
SB-2	3	1.0(E)	1.7	ND	ND	2.70	11.2(.6*)	
	6	8.1	ND	ND	ND	8.1	ND	7.4(.4*)
	9	126	669	422	1810	3,027	23.7	11.3(.6*)
	12	824(E)	13,400	6680	37,900	58,804	73.7	7.7(.4*)
	15	ND	9020	7380	46,700	63,100	58.4	ND
	18	ND	1.9	ND	ND	1.9	15.6	ND
	21	1.2	2.9	0.7(E)	2.3	7.10	ND	ND
SB-3	2.5-5.5	ND	ND	ND	ND	ND	ND	6.1(.3*)
	5.5-7	ND	1.7	1.8	12.5	16.0	ND	ND
	8	ND	1440	2050	13,600	17,090	42.3	ND
	11	1720	23,600	17,000	90,300	132,620	1040	6.2(.3*)
	13.5-16	705(E)	18,300	10,500	59,200	88,705	412	ND
	19	257	237	24.5	106	624.50	ND	ND
SB-4	3	2.0	0.5(E)	ND	1.1	3.60	ND	13.0(.7*)
	6	35.8	2.2	1.0(E)	3.0	42.00	ND	17.4(.9*)
	9	1110(E)	6790	3590	12,700	24,190	161.1	4.7(.2*)
	12	ND	10,700	9740	42,700	63,140	280	ND
	15	ND	ND	ND	0.8(E)	0.8	ND	ND
SB-5	3	3.0	3.1	19.2	16.6	41.90	ND	12.7(.6*)
	6	ND	ND	ND	ND	ND	ND	6.1(.3*)
	7-9	ND	390	876	2000	3,266	43.2	8.7(.4*)
	12	ND	ND	ND	ND	ND	ND	6.2(.3*)
	15	ND	ND	ND	ND	ND	ND	ND
	18	ND	ND	ND	ND	ND	ND	ND
SB-6	3	ND	ND	ND	ND	ND	ND	13.7(.7*)
	6	ND	ND	ND	ND	ND	ND	7.9(.4*)
	10-12	ND	10,100	8040	44,700	62,840	310	16.9(.8*)
	12-17	6.0	ND	ND	7.6	13.60	ND	ND
	21-22	ND	ND	ND	ND	ND	ND	ND
	22-23	5.6	6.0	2.7	10.0	24.30	ND	ND
	23-24	1.8	2.2	ND	2.3	6.30	ND	ND
SB-7	2-7	ND	ND	ND	ND	ND	ND	12.3(.6*)
	9-12	ND	ND	ND	ND	ND	114	7.8(.4*)
	12-15	ND	ND	ND	ND	ND	12.1	ND
	15-17	0.9(E)	ND	ND	ND	0.9	ND	ND
	17-20	ND	ND	ND	ND	ND	ND	5.4(.3*)
	20-22	ND	1.0(E)	ND	ND	1.0	ND	ND
	22-23	1.2	ND	ND	ND	1.2	ND	ND
SB-8	3	ND	ND	ND	ND	ND	ND	10.8(.5*)
	7	ND	ND	ND	ND	ND	ND	9.6(.5*)
	9	ND	ND	ND	0.7(E)	0.7	ND	6.3(.3*)
	12	ND	ND	14.7	27	41.70	14.1	6.3(.3*)
	15	ND	ND	1.3	2.7	4.00	ND	4.4(.2*)
	15-17	ND	ND	ND	ND	ND	ND	ND
	20	ND	ND	ND	ND	ND	ND	ND
	22-25	5.8	ND	ND	ND	5.8	ND	4.3(.2*)

Source: WSCI, 1992; Samples Collected May 20-23, 1991

Shaded results indicate exceedance of OCC Cleanup Standards or Background

BTEX - (Benzene, Toluene, Ethylbenzene, Xylenes) by Method 8020

TPH - Total Petroleum Hydrocarbons by Method 8015 Modified

Total Lead By Method 6010

* - Equivalent Concentration by TCLP Extraction Method

ND - Not Detected at the Practical Quantitation Limit

E - Estimated Concentration

¹Total BTEX computed by summation of BTEX compounds²Background concentration (TT, 1995b)

Investigation for Soil and Groundwater Cleanup Report
Contract No. F34650-93-D-0107-5006
Revision 0
October 10, 1995
Page 5-21

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994

Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit

Background metals concentration developed by IT Corporation (1995b)

Oklahoma Corporation Commission (OCC) Category II Clean-up Levels

Qualifier (QFR) Codes

N = Sample is outside of Matrix Spike QC limit

WOC/SVOCs: B = Analyte is found in the associated blank as well as in the sample

J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Investigation for Soil and Groundwater Cleanup Report
Contract No. F34650-93-D-0107-5006
Revision 0
October 10, 1995
Page 5-22

Well Number: Sample Number: Depth:	Background/Cleanup Levels		SB-007 A1318 3 - 4	SB-007 A1319 9 - 10	SB-007 A1175 14 - 15	SB-007 A1176 15 - 16	SB-008 A1177 3 - 4				
Parameters	Background ¹	OCC Cat. II ²	Result	QFR	Result	QFR	Result	QFR			
General Parameters (mg/kg)											
Total Petroleum Hydrocarbons		500		16	92						
Metals (mg/kg)											
Arsenic	23		2.5	1.1			1.4				
Barium	1,770		110	N	80	N	43	N			
Cadmium	0.58			0.68							
Chromium	34		8.6	17	3.8	5.2	4.6				
Lead	26		7.0	6.6	2.0	1.5	3.0				
Zinc	52		13	19	3.9	6.3	8.1				
Semi-Volatiles (mg/kg)											
2-Methylnaphthalene				0.40	1.5						
Fluorene					0.057	J					
Naphthalene				0.36	1.5						
Phenanthrene					0.14	J					
Volatiles (µg/kg)											
2-Butanone				77	JB	19	JB				
Acetone				190	JB	35	JB	7.2	JB		
Ethylbenzene		150,000		1600	D	24000	D	2.7	J	2.3	J
Methylene Chloride			2.0	JB							
Toluene		400,000			4000	D	1.1	J	1.0	J	
Xylenes (total)		1,000,000		3000	D	95000	D	9.7	9.1		

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994

Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit

¹Background metals concentration developed by IT Corporation (1995b)

²Oklahoma Corporation Commission (OCC) Category II Cleanup Levels

Qualifier (QFR) Codes

N = Sample is outside of Matrix Spike QC limit

D = Compound identified at a secondary dilution factor

VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample

J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Investigation for Soil and Groundwater Cleanup Report
 Contract No. F34650-93-D-0107-5006
 Revision 0
 October 10, 1995
 Page 5-23

Well Number: Sample Number: Depth:	Background/Cleanup		SB-008 A1178 9 - 10		SB-008 A1179 10 - 11		SB-008 A1180 17 - 18		2-2A A1354 2 - 2.5		2-2A A1355 8.5 - 9	
	Background ¹	OCC Cat. II ²	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR
Parameters												
General Parameters (mg/kg)												
Total Petroleum Hydrocarbons		500			24						1,100	
Metals (mg/kg)												
Arsenic	23											
Barium	1,770				2.9	N			2.6	N		
Cadmium	0.58		110	N*	160	N*	17	N*	240	N*	360	N*
Chromium	34		0.88	*	1.1							
Lead	26		12	*	21	*	6.9	*	15		21	
Zinc	52		4.5	N	9.2	N	1.9	N	11	N	5.1	N
			14	*	22	*	7.8	*	25		14	
Semi-Volatiles (mg/kg)												
2-Methylnaphthalene					0.77						17	
Acenaphthene											0.52	J
Dibenzofuran											0.36	J
Fluorene											0.85	J
Naphthalene					0.53						14	
Phenanthrene											2.2	
Pyrene											0.19	J
Volatiles (µg/kg)												
2-Butanone			23	J	76	J	6.5	J			2200	JB
Acetone			55	JB	160	JB	24	JB	8.0	JB		
Ethylbenzene		150,000	1.9	J	540						49000	D
Methylene Chloride			8.5	JB	7.1	JB	7.9	JB	1.7	JB		
Toluene		400,000			19	J						
Xylenes (total)		1,000,000	1.5	JB	2700	B					84000	D

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994

Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit

¹Background metals concentration developed by IT Corporation (1995b)

²Oklahoma Corporation Commission (OCC) Category II Clean-up Levels

Qualifier (QFR) Codes

N = Sample is outside of Matrix Spike QC limit

D = Compound identified at a secondary dilution factor

* = Duplicate analysis outside control limits

Metals: VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample

J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Investigation for Soil and Groundwater Cleanup Report
 Contract No. F34650-93-D-0107-5006
 Revision 0
 October 10, 1995
 Page 5-24

Well Number: Sample Number: Depth:	Background/Cleanup		2-2A A1356 10.5 - 11		2-4A A1358 4 - 5		2-4A A1359 8.5 - 9		2-4A A1360 12 - 13		2-50B A1341 3 - 4	
	Parameters	Background ¹	OCC Cat. II ²	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result
General Parameters (mg/l)												
Total Petroleum Hydrocarbons												
			500	340		110		61		99		
Metals (mg/kg)												
Arsenic	23			1.1	N	2.3						2.5
Barium	1,770			97	N*	370	N*	160	N*	870	N*	160
Cadmium	0.58					0.68						0.47
Chromium	34			15		14		10		6.3		11
Lead	26			4.7	N	13		3.5		2.0		7.6
Zinc	52			15		21		10		5.4		17
Semi-Volatiles (mg/kg)												
2-Methylnaphthalene				3.3				0.92		4.9		
Acenaphthene				0.24	J				J	0.04		
Anthracene				0.085	J							
Dibenzofuran				0.16	J							
Fluorene				0.35						0.03	J	
Naphthalene				1.3				0.96		4.4		
Phenanthrene				0.95						0.07	J	
Pyrene				0.07	J							
bis(2-Ethylhexyl)phthalate						0.18	J	0.07	J			
Volatiles (µg/kg)												
2-Butanone				20	JB	200	JB	16	JB	5100	JB	7.3
Acetone				110	B	600	B	28	JB		JB	11
Benzene		5,000		87								
Chlorobenzene										370	J	
Ethylbenzene		150,000		250	D	110		240		18,000		0.8
Methylene Chloride				5.9	JB			5.2	JB			1.0
Toluene		400,000				89	B	1.4	JB	12,000	B	1.0
Xylenes (total)		1,000,000		44		270		1600		10,000	D	1.4

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994

Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit

¹Background metals concentration developed by IT Corporation (1995b)

²Oklahoma Corporation Commission (OCC) Category II Clean-up Levels

Qualifier (QFR) Codes

N = Sample is outside of Matrix Spike QC limit

D = Compound identified at a secondary dilution factor

* = Duplicate analysis outside control limits

VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample

J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Investigation for Soil and Groundwater Cleanup Report
Contract No. F34650-93-D-0107-5006
Revision 0
October 10, 1995
Page 5-25

Well Number: Sample Number: Depth:	Background/Cleanup		2-50B A1342 9 - 10		2-50B A1343 10 - 12		2-51A A1350 1 - 1.5	
	Background ¹	OCC Cat. II ²	Result	QFR	Result	QFR	Result	QFR
Parameters								
General Parameters (mg/kg)								
Total Petroleum Hydrocarbons		500	44		11		30	
Metals (mg/kg)								
Arsenic	23		1.8		2.8		2.1	N
Barium	1,770		92	N	230	N	110	
Cadmium	0.58				1.4			
Chromium	34		19		24		14	
Lead	52		3.2		6.0		7.4	N
Zinc	79		24		29		14	
Semi-Volatiles (mg/kg)								
2-Methylnaphthalene			0.62		0.55			
Di-n-butylphthalate					0.049	J		
Naphthalene			0.44		0.36			
bis(2-Ethylhexyl)phthalate							0.047	J
Volatiles (µg/kg)								
2-Butanone			83	JB	33	JB		
Acetone			290	JB	170	JB	6.2	JB
Benzene		5,000					1.0	JB
Ethylbenzene		150,000	250		64			
Methylene Chloride							2.7	JB
Toluene		400,000	100		12			
Xylenes (total)		1,000,000	1200		440			

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994

Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit

¹Background metals concentration developed by IT Corporation (1995b)

²Oklahoma Corporation Commission (OCC) Category II Clean-up Levels
Qualifier (QFR) Codes

N = Sample is outside of Matrix Spike QC limit

VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample

J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Investigation for Soil and Groundwater Cleanup Report
 Contract No. F34650-93-D-0107-5006
 Revision 0
 October 10, 1995
 Page 5-26

Well Number: Sample Number: Depth:	Parameters	Background/Cleanup		2-51A A1351 6 - 6.5		2-51A A1352 12 - 12.5		2-51A A1353 18 - 18.5		2-51B A1334 6 - 7		2-51B A1335 9 - 10	
		Background ¹	OCC Cat. II ²	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR
	General Parameters (mg/kg)												
	Total Petroleum Hydrocarbons		500										
	Metals (mg/kg)												
	Arsenic	23		4.9	N	1.9	N	1.5	N	14	N	5.5	N
	Barium	1,770		810		62		180		280	N	5000	N
	Cadmium	0.58		0.73						1.6		0.58	
	Chromium	34		12		16		12		16		16	
	Lead	26		8.2	N	6.2	N	4.1	N	22		9.0	
	Selenium	8.2								16			
	Zinc	52		16		17		12		23		23	
	Semi-Volatiles (mg/kg)												
	Di-n-octylphthalate									0.38	B	0.27	JB
	Volatiles (ug/kg)												
	2-Butanone			7.4	JB	5.2	JB	5.8	JB				
	Acetone			20	JB	13	JB	11	JB	5.1	JB	32	JB
	Benzene		5,000	1.0	JB								
	Chlorobenzene									0.5	J		
	Ethylbenzene		150,000							0.2	J		
	Methylene Chloride			2.4	JB	2.2	JB	13	B	6.6	JB	13	B

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994

Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit

¹Background metals concentration developed by IT Corporation (1995b)

²Oklahoma Corporation Commission (OCC) Category II Clean-up Levels

Qualifier (QFR) Codes

N = Sample is outside of Matrix Spike QC limit

VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample

J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Investigation for Soil and Groundwater Cleanup Report
 Contract No. F34650-93-D-0107-5006
 Revision 0
 October 10, 1995
 Page 5-27

Well Number: Sample Number: Depth:	Background/Cleanup		2-51B AI336 11 - 12		2-52A AI347 1 - 2		2-52A AI348 8 - 9		2-52A AI349 10 - 10.5		2-52B AI338 4 - 5	
	Background	OCC Cat. II ¹	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR
General Parameters (mg/kg)												
Total Petroleum Hydrocarbons												
Metals (mg/kg)												
Arsenic	23				2.4	N.	4.4	N	1.8	N	2.8	N
Barium	1,770		63	N	160	N	120	N	120	N	260	
Cadmium	0.58		0.58								1.0	
Chromium	34		12		12	*	13	*	19	*	15	
Chromium VI	0.16										0.42	
Lead	26		5.5		11	N	7.1	N	6.7	N	8.0	N
Zinc	52		14		21	*	15	*	19	*	25	
Semi-Volatiles (mg/kg)												
2-Methylnaphthalene			0.19	J					1.1			
Di-n-octylphthalate			0.24	JB							0.07	JB
Naphthalene			0.13	J					0.88			
Volatiles (µg/kg)												
2-Butanone			21	JB	3.1	JB			40	JB		
Acetone			76	JB	12	JB	17	JB	100	B		
Benzene		5,000			4.8	J			47			
Ethylbenzene		150,000	4.9	J					92			
Methylene Chloride			0.9	JB	2.9	JB	3.2	JB	4.8	JB	8.3	JB
Xylenes (total)		1,000,000	65	B					71			

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994

Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit

¹Background metals concentration developed by IT Corporation (1995b)

²Oklahoma Corporation Commission (OCC) Category II Clean-up Levels

Qualifier (QFR) Codes

N = Sample is outside of Matrix Spike QC limit

* = Duplicate analysis outside control limits

VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample

J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Investigation for Soil and Groundwater Cleanup Report
Contract No. F34650-93-D-0107-5006
Revision 0
October 10, 1995
Page 5-28

Well Number: Sample Number: Depth:	Background/Cleanup	2-52B A1339 5.5 - 7	2-52B A1340 12 - 13
Parameters	Background	Result	Result
Metals (mg/kg)			
Arsenic	23	2.9 N	1.5 N
Barium	1,770	320	76
Cadmium	0.58	0.79	1.1
Chromium	34	16	16
Lead	26	6.8 N	5.3 N
Zinc	52	22	18
Semi-Volatiles (mg/kg)			
Di-n-octylphthalate		0.15 JB	0.31 JB
Volatiles (µg/kg)			
Acetone		17 JB	10 JB
Methylene Chloride		7.6 JB	7.6 JB

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994

Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit

¹Background metals concentration developed by IT Corporation (1995b)

²Oklahoma Corporation Commission (OCC) Category II Clean-up Levels

Qualifier (QFR) Codes

N = Sample is outside of Matrix Spike QC limit

VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample

J = Concentration is an estimated value

Table 5-10
Concentrations of Constituents Detected in Groundwater Samples
Collected From Temporary Groundwater Probes
Area A Service Station

Location	Constituent Concentrations (µg/l)																		
	Fuel Related Constituents										Chlorinated Organic Constituents								
	Benzene	Isopropyl benzene	Ethylbenzene	Naphthalene	N-Propylbenzene	Toluene	1,2,4-Trimethylbenzene	1,3,5-Trimethylbenzene	O-xylene	M-P-xylene	Chloroform	1,2-Dichlorobenzene	1,2 Dichloroethane	Cis-1,2-dichloroethene	Trans-1,2-dichloroethene	Cis-1,3-dichloropropene	Methylene Chloride	Trichloroethene	Vinyl Chloride
OCC Cat. II Standards	50	7,000				10,000			100,000										
CPT-1	2,580	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	211	102	<100	<400	<100	243
CPT-2	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	41.6**	<10	<10
CPT-3	7,830	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<2000	<500	<500
CPT-4	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	20.4	<5.0	<5.0	<5.0	<20.0	<5.0	<5.0
CPT-5	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.44	<20.0	24.4	<5.0
CPT-7	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<20.0	<5.0	<5.0
CPT-19	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<20.0	<5.0	<5.0
CPT-20	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<20.0	<5.0	<5.0
CPT-22	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<20.0	<5.0	<5.0
CPT-25	3,620	<250	298	<250	<250	<250	<250	<250	<250	<250	<250	<250	<250	<250	<250	<250	<1000	<250	<250
CPT-27	591	69.9	329	191	99.9	392	670	205	526	1,200	<50	<50	<50	<50	<50	<50	<200	<50	<50
CPT-29	5,680	<250	918	<250	<250	1,640	431	<250	<250	643	<250	<250	1,090	1,260	<250	<250	<1000	<250	<250
CPT-30	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<20.0	<5.0	<5.0
CPT-31	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<20.0	<5.0	<5.0
CPT-35	2,020	<100	417	<100	<100	<100	<100	<100	<100	<100	<100	161	575	2,270	<100	<100	<400	<100	276
CPT-38	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	32.7	<5.0	<5.0	<20.0	63.6	<5.0
CPT-41	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<20.0	<5.0	<5.0
CPT-42	<5.0	<5.0	11.5	<5.0	<5.0	<5.0	8.03	<5.0	<5.0	12.6	<5.0	<5.0	26.4	<5.0	<5.0	<5.0	<20.0	<5.0	<5.0
CPT-43	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<20.0	<5.0	<5.0
CPT-44	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<20.0	<5.0	<5.0

Indicates constituent concentration is above the OCC Category II Cleanup Standard.
 Samples analyzed using EPA Method 8260 (USEPA, 1986).

**Analytical Results for Groundwater
1993/1994 and 1994/1995**

At

Well ID	Sample Event	1,2,4-Trimethylbenzene	1,2-Dichloroethane	1,2-Dichloropropane	1,3,5-Trimethylbenzene	2-Butanone	4-Isopropyltoluene	Acetone	Benzene	Carbon Tetrachloride	Chlorobenzene
OCC Category II Cleanup Standards									50		
Upper Saturated Zone											
70	94-95	<1 U	<1 U	<1 U	<1 U		<1 U		<1 U	<1 U	<1 U
2-2	93-94		61	<5 U		<100 U		<100 U	330 D	<5 U	1.5 J
2-2	94-95	240	<25 U	<25 U	42		<25 U		1100 D	<25 U	<25 U
2-3	93-94		<5 U	<5 U		6.7 J		<100 U	3700 D	<5 U	<5 U
2-3	94-95	<1 U	<1 U	<1 U	<1 U		<200 U		2	<1 U	<1 U
2-3	94-95	<200 U	<200 U	<200 U	<200 U		<200 U		920	<200 U	<200 U
2-4	93-94		<250 U	<250 U		<5000 U		<5000 U	6400 D	<250 U	<250 U
2-50B	93-94		<500 U	<500 U		<10000 U		<10000 U	15000 D	<500 U	<500 U
2-51B	93-94		180	14 J		<500 U		<500 U	1400 D	<25 U	<25 U
2-51B	94-95	24	<10 U	<10 U	<10 U		1 DJ		530 E	<10 U	<10 U
2-52B	93-94		<5 U	<5 U		<100 U		14 J	<5 U	<5 U	<5 U
2-52B	94-95	<1 U	<1 U	<1 U	<1 U		2		<1 U	<1 U	<1 U
2-145B	94-95	<1 U	<89 U	<81 U	<1.1 U	<96 U	<0.9 U	3.9	<84 U	<93 U	<68 U
2-145B	94-95	<1 U	<89 U	<81 U	<1.1 U	<96 U	<0.9 U	2	<84 U	<93 U	<68 U
2-149B	94-95	<1 U	2.3	<81 U	<1.1 U	<96 U	<0.9 U	<1.1 U	<84 U	<93 U	<68 U
2-163B	94-95	<1 U	160	1.5	<1.1 U	<96 U	<0.9 U	<1.1 U	<84 U	<93 U	<68 U
2-164B	94-95	<1 U	1.3	<81 U	<1.1 U	<96 U	<0.9 U	<1.1 U	<84 U	<93 U	<68 U
2-165B	94-95	<1 U	<89 U	<81 U	<1.1 U	<96 U	<0.9 U	<1.1 U	<84 U	<93 U	<68 U
2-166B	94-95	<1 U	<89 U	<81 U	<1.1 U	<96 U	<0.9 U	<1.1 U	<84 U	<93 U	<68 U
2-173B	94-95	<1 U	<89 U	<81 U	<1.1 U	<96 U	<0.9 U	1.8	<84 U	<93 U	<68 U
Lower Saturated Zone											
2-2A	93-94		<5 U	<5 U		<100 U		<100 U	<5 U	24	<5 U
2-2A	94-95	<1 U	0.6 UJ	<1 U	<1 U		<1 U		<1 U	13	<1 U
2-4A	93-94		<5 U	<5 U		<100 U		11 J	<5 U	<5 U	<5 U
2-4A	93-94		<5 U	<5 U		<100 U		<100 U	<5 U	<5 U	<5 U
2-4A	94-95	<1 U	1	<1 U	<1 U		<1 U		<1 U	0.3 J	<1 U
2-51A	93-94		<5 U	<5 U		<100 U		11 J	<5 U	4.2 J	<5 U
2-51A	94-95	<1 U	2	<1 U	<1 U		<1 U		<1 U	6	<1 U
2-52A	93-94		<5 U	<5 U		<100 U		<100 U	<5 U	3.1 J	<5 U
2-52A	94-95	<1 U	0.4 UJ	<1 U	<1 U		<1 U		<1 U	4	<1 U
2-149A	94-95	<1 U	<89 U	<81 U	<1.1 U	9.6	<0.9 U	11.4	10.5	<93 U	<68 U

Notes:

1. Only detected compounds are provided in this table.

Groundwater samples were analyzed by EPA Method 8240

2. Qualifier codes are provided after the analytical results. Codes are as follows:

U-Compound was analyzed for but was not detected.

J-Estimated Value.

D-Dilution run. Initial run outside linear range of instrument.

N-Spiked Sample recovery not within control limits.

3. Shaded results indicate exceedance of the OCC Cleanup Standard.

Table 5-11
Analytical Results for Groundwater Samples - Volatile Organic Compounds
1993/1994 and 1994/1995 Groundwater Sampling Programs
Area A Service Station

Parameters (µg/l)															
2-Butanone	4-Isopropyltoluene	Acetone	Benzene	Carbon Tetrachloride	Chlorobenzene	Chloroform	cis-1,2-Dichloroethene	Ethylbenzene	Isopropylbenzene	Methylene Chloride	n-Butylbenzene	Naphthalene	sec-Butylbenzene	tert-Butylbenzene	Tetrachloroethylene
			50					7,000							
0 U	<1 U	<100 U	<1 U	<1 U	<1 U	<1 U	<1 U	<1 U	<1 U	<4 U	<2 U	<4 U	<1 U	<1 U	<1 U
0 U	<25 U	<100 U	330 D	<1 U	1.5 J	<1 U	64	79	<1 U	<10 U	<2 U	2.4 J	<1 U	<1 U	<1 U
J	<200 U	<100 U	1100 D	<25 U	<25 U	<50 U	40	740	27	<100 U	5 U	56 J	<25 U	<25 U	<25 U
0 U	<200 U	<5000 U	3100 D	<1 U	<1 U	<1 U	160	6.2	<1 U	<10 U	<2 U	4.4 J	<1 U	<1 U	<1 U
00 U	<200 U	<10000 U	2	<200 U	<200 U	<200 U	<1 U	<200 U	<200 U	<4 U	<2 U	<4 U	<200 U	<200 U	<200 U
0 U		<500 U	920	<250 U	<250 U	<250 U	2900	1700		<800 U	<400 U	<800 U	<200 U	<200 U	<250 U
0 U	1 DI		15000	<500 U	<500 U	<500 U	480 J	2000		<500 U		470 D			<500 U
0 U			1400 D	<25 U	<25 U	<25 U	<25 U	23 J		<50 U		5.6 J			<25 U
0 U	2	14 J	530 E	<10 U	<10 U	0.9 U	<10 U	18	4 J	<20 U	3 U	1 U	<10 U	<10 U	<10 U
5 U	<0.9 U	3.9	<1 U	<1 U	<1 U	0.4 U	<1 U	8	6	<4 U	2 U	8	2	0.3 U	<1 U
5 U	<0.9 U	2	<84 U	<93 U	<68 U	<86 U	<82 U	<81 U	<0.7 U	<85 U	<1.4 U	<57 U	<1.2 U	<1.1 U	<66 U
5 U	<0.9 U	<1.1 U	<84 U	<93 U	<68 U	<86 U	<82 U	<81 U	<0.7 U	<85 U	<1.4 U	<57 U	<1.2 U	<1.1 U	<66 U
5 U	<0.9 U	<1.1 U	<84 U	<93 U	<68 U	<86 U	<82 U	<81 U	<0.7 U	<85 U	<1.4 U	<57 U	<1.2 U	<1.1 U	<66 U
5 U	<0.9 U	<1.1 U	<84 U	<93 U	<68 U	<86 U	<82 U	<81 U	<0.7 U	<85 U	<1.4 U	<57 U	<1.2 U	<1.1 U	<66 U
5 U	<0.9 U	<1.1 U	<84 U	<93 U	<68 U	<86 U	<82 U	<81 U	<0.7 U	<85 U	<1.4 U	<57 U	<1.2 U	<1.1 U	<66 U
5 U	<0.9 U	<1.1 U	<84 U	<93 U	<68 U	<86 U	<82 U	<81 U	<0.7 U	<85 U	<1.4 U	<57 U	<1.2 U	<1.1 U	<66 U
5 U	<0.9 U	1.8	<84 U	<93 U	<68 U	<86 U	<82 U	<81 U	<0.7 U	<85 U	<1.4 U	<57 U	<1.2 U	<1.1 U	<66 U
0 U	<1 U	<100 U	<1 U	24	<1 U	<1 U	<1 U	<1 U	<1 U	<10 U	<2 U	<10 U	<1 U	<1 U	<1 U
0 U		11 J	<1 U	13	<1 U	2	0.2 U	<1 U	<1 U	<4 U	<2 U	<4 U	<1 U	<1 U	<1 U
0 U	<1 U	<100 U	<1 U	<1 U	<1 U	<1 U	<1 U	<1 U	<1 U	<10 U	<2 U	<10 U	<1 U	<1 U	<1 U
0 U	<1 U		<1 U	0.3 J	<1 U	1 U	0.5 U	<1 U	<1 U	<4 U	<2 U	<4 U	<1 U	<1 U	0.1
0 U	<1 U	11 J	<1 U	4.2 J	<1 U	<1 U	<1 U	<1 U	<1 U	<10 U	<2 U	<10 U	<1 U	<1 U	<1 U
0 U	<1 U	<100 U	<1 U	6	<1 U	1 U	2	<1 U	<1 U	<4 U	<2 U	<4 U	<1 U	<1 U	0.2
	<0.9 U	11.4	<1 U	3.1 J	<1 U	<1 U	0.8 U	<1 U	<1 U	<10 U	<2 U	<4 U	<1 U	<1 U	<1 U
			10.5	<93 U	<68 U	<86 U	<82 U	1.1	3	<85 U	<1.4 U	<57 U	<1.2 U	<1.1 U	<66 U

le.
 hod 8240
 ults. Codes are as follows:
 tected.

of instrument.
 limits.
 eanup Standard.

2

Page 5-34

:ters ($\mu\text{g/l}$)

Concentrations (µg/l)													
Concentration	Isopropylbenzene	Methylene Chloride	n-Butylbenzene	Naphthalene	sec-Butylbenzene	tert-Butylbenzene	Tetrachloroethylene	Toluene	trans-1,2-Dichloroethylene	Trichloroethene	Vinyl Chloride	Xylenes (Total)	
0.000								10,000				100,000	
U	<1	<4	<2	<4	<1	<1	<1	<1	<4	<1	<1	<1	
U	27	<100	5	2.4	<25	<25	<25	32	<4	210	<10	81	
U	<200	<400	<400	4.4	<200	<200	<200	130	<100	130	1	730	
U		<500		4.4				16	<4	260	39	27	
U		<1000		4.4				43	<4	43	<1	<1	
U	4	<50	<20	3	1	<10	<10	17	<25	15	<50	51	
U	6	<40	<10	<10	2	0.3	<4	6	<40	<10	<10	11	
U	<0.7	<85	<1.4	<5.7	<1.2	<1.1	<66	<87	<85	0.8	<1	<1	
U	<0.7	<85	<1.4	<5.7	<1.2	<1.1	<66	<87	<85	<92	<9	<1.3	
U	<0.7	<85	<1.4	<5.7	<1.2	<1.1	<66	<87	<85	2.6	<9	<1.3	
U	<0.7	<85	<1.4	<5.7	<1.2	<1.1	<66	<87	<85	4.1	<9	<1.3	
U	<0.7	<85	<1.4	<5.7	<1.2	<1.1	<66	<87	<85	<92	<9	<1.3	
U	<0.7	<85	<1.4	<5.7	<1.2	<1.1	<66	<87	<85	<92	<9	<1.3	
U	<0.7	<85	<1.4	<5.7	<1.2	<1.1	<66	<87	<85	10.2	<9	<1.3	
U	<0.7	<85	<1.4	<5.7	<1.2	<1.1	<66	<87	<85	2.4	<9	<1.3	
U	<4	<40	<10	<40	<4	<4	<4	<4	<4	6.8	<10	<4	
U	<4	<40	<10	<40	<4	<4	<4	<4	<4	32	<4	<4	
U	<4	<40	<10	<40	<4	<4	<4	<4	<4	13	<10	<4	
U	<4	<40	<10	<40	<4	<4	<4	<4	<4	13	<10	<4	
U	<4	<40	<10	<40	<4	<4	0.1	<4	<4	38	<4	<4	
U	<4	<40	<10	<40	<4	<4	<4	2.6	<4	29	<10	<4	
U	<4	<40	<10	<40	<4	<4	0.2	<4	0.1	130	<4	<4	
U	<4	<40	<10	<40	<4	<4	<4	<4	<4	15	<10	<4	
U	<4	<40	<10	<40	<4	<4	<4	<4	<4	36	<4	<4	
U	3	<85	<1.4	<5.7	<1.2	<1.1	<66	2.5	<85	<92	<9	<1.3	

③

Table 5-12
 Analytical Results for Groundwater Samples - Semivolatile Organic Compounds
 1993/1994 and 1994/1995 Groundwater Sampling Programs
 Area A Service Station

Well ID	Sample Event	Parameters (µg/l)										
		2,4-Dimethylphenol	2-Methylnaphthalene	2-Methylphenol	4-Methylphenol	Acenaphthene	Bis(2-Ethylhexyl)Phthalate	D-n-Butylphthalate	Dibenzofuran	Dimethylphthalate	Fluorene	Isophorene
Upper Saturated Zone	70	<10	<10	<10	10	<10	18	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	2.9	<10	<10	<10	<10	<10
	93-94	<10	5.6	<10	<10	<10	1	<10	<10	<10	<10	<10
	94-95	<10	15	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-2	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-3	<10	4.6	<10	<10	<10	<10	<10	<10	<10	<10	<10
	93-94	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-3	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-4	<10	280	<10	26	1.5	4.8	<10	<10	<10	<10	<10
	93-94	<10	1.50	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-50B	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	93-94	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Lower Saturated Zone	2-51B	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-52B	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-145B	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-146B	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-149B	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-163B	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-164B	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-165B	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-166B	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-173B	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Upper Saturated Zone	2-2A	<10	<10	<10	<10	<10	1.3	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-2A	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-4A	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	93-94	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-4A	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-51A	<10	<10	<10	<10	<10	7.1	<10	<10	<10	<10	<10
	93-94	<10	<10	<10	<10	<10	4.3	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-52A	<10	<10	<10	<10	<10	5.2	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-52A	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	94-95	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	2-149A	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10

Notes:
 1. Only detected compounds are provided in this table.
 Groundwater samples were analyzed by EPA Method 8270
 2. Qualifier codes are provided after the analytical results. Codes are as follows:
 U-Compound was analyzed for but was not detected.
 J-Estimated Value.
 D-Dilution run. Initial run outside linear range of instrument.
 N-Spiked Sample recovery not within control limits.

Table 5-13
 Analytical Data for Groundwater Samples - Metals
 1993/1994 and 1994/1995 Groundwater Sampling Programs
 Area A Service Station

		Parameters (µg/l)												
	Well ID	Sample Event	Arsenic	Barium	Chromium VI	Chromium, Total	Copper	Iron	Lead	Mercury	Nickel	Selenium	Silver	Zinc
Upper Saturated Zone	70	94-95	1.4	10	<1	110	<2.5	280	0.5	0.02	23	0.3	1	U
	2-2	93-94	<1	380	U	<1	U	<0.3	U	<0.02	U	<10	<1	U
	2-2	94-95	5	4790	<1	<1	U	<1	U	0.22	18	<10	0.45	U
	2-3	93-94	<1	79	U	<1	<2.5	220	<0.3	<0.02	U	<10	<1	U
	2-3	94-95	<0.3	80	U	<1	U	<0.5	U	<0.02	U	<10	<1	U
	2-3	94-95	<0.3	90	U	<1	U	<0.5	U	<0.02	U	<10	<1	U
	2-4	93-94	<1	24	U	<1	<2.5	92	0.81	<0.02	U	<10	<1	U
	2-50B	93-94	1.3	660	<1	U	<2.5	1700	1.9	<0.02	UN	<10	<1	U
	2-51B	93-94	<1	190	U	2.3	<2.5	1200	0.81	<0.02	U	<10	<1	U
	2-51B	94-95	6.5	3230	<1	90.5	<2.5	U	40.5	0.25	131	<10	<1	U
	2-52B	93-94	<1	27	U	2.4	<2.5	1500	1.3	<0.02	U	<10	<1	U
	2-52B	94-95	3	298	U	19	U	U	16.5	0.29	27.5	<10	<1	U
	2-145B	94-95	<1.55	51	U	<3.5	U	U	<25	<2	9.6	<10	<1	U
	2-146B	94-95	<1.55	510	U	<3.5	U	U	<25	<2	9.6	<10	<1	U
Lower Saturated Zone	2-149B	94-95	<1.55	360	U	21	U	U	<25	<2	9.6	<10	<1	U
	2-163B	94-95	<1.55	270	U	4.4	U	U	<25	<2	8.6	<10	<1	U
	2-164B	94-95	<1.55	380	U	<3.5	U	U	<25	<2	1.7	<10	<1	U
	2-165B	94-95	<1.55	46	U	<3.5	U	U	<25	<2	22	<10	<1	U
	2-166B	94-95	<1.55	56	U	<3.5	U	U	<25	<2	<35	<10	<1	U
	2-173B	94-95	<1.55	830	U	5.4	U	U	<25	<2	<35	<10	<1	U
	2-2A	93-94	<1	49	N	1.3	4.4	210	<0.3	<0.02	UN	10	<1	9.7
	2-2A	94-95	<2	617	U	30	U	U	1	<0.2	U	<10	<1	U
	2-4A	93-94	3.7	<20	UN	1.7	<2.5	96	<0.3	<0.02	UN	<10	<1	2
	2-4A	93-94	3.7	<20	UN	2.1	<2.5	110	<0.3	<0.02	UN	<10	<1	2.3
2-4A	94-95	6	788	U	378	U	U	2.5	0.24	367	<10	0.4	U	
2-51A	93-94	1.8	<20	U	1.7	<2.5	200	<0.3	<0.02	UN	<10	<1	U	
2-51A	94-95	4.5	1320	U	262	U	U	6.5	0.25	169	<10	2.5	U	
2-52A	93-94	<1	48	N	1.9	<2.5	54	0.32	<0.02	UN	<10	<1	U	
2-52A	94-95	<2	608	U	6	U	U	1	0.27	68	<10	<1	U	
2-149A	94-95	<1.55	120	U	<3.5	U	U	<0.25	<0.2	<0.35	<10	<1	U	

Notes:
 1. Only detected compounds are provided in this table.
 2. Qualifier codes are provided after the analytical results. Codes are as follows:
 U-Compound was analyzed for but was not detected.
 J-Estimated Value.
 D-Dilution run. Initial run outside linear range of instrument.
 N-Spiked Sample recovery not within control limits.

Table 5-14
Analytical Results for Groundwater Samples -
1993/1994 and 1994/1995 Groundwater
Area A Service St

		Parameters (mg/l)																			
Well ID	Sample Event	Alkalinity, Titrimetric	Calcium	Chemical Oxygen Demand	Chloride by Ion Chrom.	Magnesium	Manganese	Nitrate and Nitrite	Potassium	Silica	Sodium										
OCC Category II Cleanup Standards																					
Upper Saturated Zone																					
70	94-95	640	140 N		380	63 N	0.5	<0.050 U	<5.0 U	8.7	250 N										
2-2	93-94																				
2-2	94-95																				
2-3	93-94	630	110 N		210	58 N	0.8	<0.050 U	<5.0 U	12	210 N										
2-3	94-95																				
2-3	94-95																				
2-4	93-94	630	130 N		350	64 N	0.38	0.15	<5.0 U	10	260 N										
2-50B	93-94																				
2-51B	93-94																				
2-51B	94-95	640	240		1000	120	0.74	<0.050 U	<5.0 U	20	390										
2-52B	93-94																				
2-52B	94-95																				
2-145B	94-95	300	30	35	12	17	0.38	<0.050 U	<5.0 U	12	89										
2-146B	94-95																				
2-149B	94-95																				
2-163B	94-95																				
2-164B	94-95																				
2-165B	94-95																				
2-166B	94-95																				
2-173B	94-95																				
Lower Saturated Zone																					
2-2A	93-94											370	110 N	30	190	50 N	0.08 N	3.9	9.4 N	26	73 N
2-2A	94-95																				
2-4A	93-94	190	57 N		170	22 N	0.02 N	2.4	14 N	43	92 N										
2-4A	93-94																				
2-4A	94-95	190	58 N		140	23 N	0.032 N	2.5	15 N	41	95 N										
2-51A	93-94																				
2-51A	94-95	110	37		140	16	0.04	3	15	36	67										
2-52A	93-94																				
2-52A	94-95																				
2-149A	94-95																				
2-52A	93-94	350	98 N		140	46 N	0.03 N	5.9	6.9 N	20	66 N										
2-52A	94-95																				
2-149A	94-95																				

Notes:

- Only detected compounds are provided in this table.
- Qualifier codes are provided after the analytical results. Codes are as follows:
 U-Compound was analyzed for but was not detected.
 J-Estimated Value.
 D-Dilution run. Initial run outside linear range of instrument.
 N-Spiked Sample recovery not within control limits.

Table 5-14

ical Results for Groundwater Samples - General Groundwater Parameters
1993/1994 and 1994/1995 Groundwater Sampling Programs

Area A Service Station

Parameters (mg/l)											
Nitrate and Nitrite	Potassium	Silica	Sodium	Sulfate by Ion Chrom.	Total Dissolved Solids	Total Kjeldahl Nitrogen	Total Organic Carbon	Total Phosphorus	Total Suspended Solids	TPH - IR	Turbidity (in NTU)
										10	
<0.050 U	<5.0 U	8.7	250 N	12	804	0.25 UN	2	<0.1 U	130	1.4	
<0.050 U	<5.0 U	12	210 N	15	1200		15				
					1220		13.6				
					1000	0.49 N	11	<0.1 U	43	2.4	
					297		9				
					897		11				
0.15	<5.0 U	10	260 N	110	1300	0.32 N	11	ISSI ND	<20 U	93	
<0.050 U	<5.0 U	24	250	4.6	1400	0.3 N	14	0.14	360	46	
<0.050 U	<5.0 U	20	390	9.5	2600	0.46 N	29	0.27 N	710	2.4	
					1290		18.7				
<0.050 U	<5.0 U	12	89	18	400	0.25 N	1.5	0.29 N	800	1.2	
					376		2.4		376		
					1000		2				19
					780		4				120
					990		<1 U				240
					1700		5				11
					920		1				11
					1000		1				3.7
					900		<1 U				13
					590		2				36
3.9	9.4 N	26	73 N	26	650	<0.25 U	<1.0 U	<0.1 U	58	<1.0 U	
2.4	14 N	43	92 N	40	706		2.2				
2.5	15 N	41	95 N	43	450	<0.25 U	<1.0 U	<0.1 U	96	<1.0 U	
					460	<0.25 U	<1.0 U	<0.1 U	93	<1.0 U	
					631		2.1				
3	15	36	67	29	490	0.7 N	2.7	0.32	110	<0.9 U	
					653		3				
5.9	6.9 N	20	66 N	38	600	<0.25 U	<1.0 U	<0.1 U	52	<0.9 U	
					596		1.9				
					930		5				10

Soil And Groundwater Report
Contract No. F34650-93-D0107, 5006

Revision 0

October 10, 1995

Page 5-37

ameters

	Total Organic Carbon	Total Phosphorus	Total Suspended Solids	TPH - IR	Turbidity (in NTU)
				10	
UN	2				
	15	<0.1 U	130	1.4	
	13.6				
N	11	<0.1 U	43	2.4	
	9				
	11				
N	11	ISSI ND	<20 U	93	
N	14	0.14	360	46	
N	29	0.27 N	710	2.4	
	18.7				
N	1.5	0.29 N	800	1.2	
	2.4		376		
	2				19
	4				120
	<1 U				240
	5				11
	1				11
	1				3.7
	<1 U				13
	2				36
U	<1.0 U	<0.1 U	58	<1.0 U	
	2.2				
U	<1.0 U	<0.1 U	96	<1.0 U	
U	<1.0 U	<0.1 U	93	<1.0 U	
	2.1				
N	2.7	0.32	110	<0.9 U	
	3				
U	<1.0 U	<0.1 U	52	<0.9 U	
	1.9				
	5				10

3

APPENDIX D

TINKER AFB WELL INSTALLATION STANDARDS

12.0 WELL INSTALLATION STANDARDS

12.1 Borehole Drilling

12.1.1 General: Each borehole shall be drilled in accordance with these procedures and applicable EPA and ASTM procedures. Drilling operations and well installation shall be supervised by an experienced and degreed geologist/hydrogeologist.

12.1.2 Location of Boreholes: The approximate location and depth of the boreholes and the number of boreholes will be specified in the Delivery Order. The exact location, depth, and number of boreholes for the study shall be determined in the field by the contractor in consultation with the authorized Environmental Management Directorate representative.

12.1.3 Drilling Fluid Additives: Bentonite is the only drilling fluid additive allowed. No organic additives shall be used. Exception is usually made for some high yield bentonites to which the manufacturer has added a small quantity of polymer additive. The use of any bentonite must be approved by the Contracting Officer prior to the arrival on-site of the drilling equipment (rigs). This includes bentonites (powders, pellets, etc.) intended for drilling mud, grout seals, etc. The following data shall be submitted in writing through the Environmental Management Directorate (OC-ALC/EM) to the Contracting Officer as part of the approval request:

- a. Brand Name(s)
- b. Manufacturer(s)
- c. Manufacturer's address(es) and telephone number(s)
- d. Product description(s) from package label(s) and manufacturer's brochure(s)
- e. Intended use(s) for this product
- f. Name and phone number of approving State or Federal EPA representative. Allow six working days from the time of receipt by EM for Contracting Officer approval.

12.2 Water Sources

12.2.1 On-site Requirements: The source(s) of any water to be used in drilling, grouting, sealing, purging, well installation, or equipment washing shall be approved by the Contracting Officer or authorized representative prior to arrival of the drilling equipment on-site. Water source(s) shall meet the following requirements:

- a. A deep aquifer origin (greater than 200 feet below ground surface)
- b. Upgradient of potential contaminant sources
- c. Free of survey related contaminants by virtue of pre-testing

- d. Water shall not be treated or filtered
- e. 24-hours-a-day and 7-days-a-week access
- f. Water flow sufficient to allow the filling of a 500-gallon tank in less than 20 minutes
- g. The use of only one designated tap for access
- h. Surface water bodies shall not be used

12.2.2 Off-site Sources: If a suitable source exists on-site, the contractor shall use that source. If no on-site water is available, the contractor shall locate a potential source(s) and submit the following data in writing through the Environmental Management Directorate (EM) to the Contracting Officer for approval prior to the arrival of any drilling equipment on-site:

- a. Owner/Address/Telephone Number
- b. Location of Tap/Address
- c. Type of Source (well, to include static water level, date measured, well depth, and aquifer description, pond, river, etc).
- d. Type of treatment prior to tap (chlorination, fluoridation, softening, etc).
- e. Time of Access (24-hours per day, 5-days per week, etc).
- f. Cost per gallon
- g. Results and dates of all available chemical analysis over past two years. Allow six working days from the time of receipt by EM for Contracting Officer approval. The contractor has the responsibility to procure, transport, and store the water required for project needs in a manner to avoid the chemical degradation of the water once obtained.

12.2.3 Tanks: Portable recirculation tanks are required for mud/water rotary formations and similar requirements. The use of dug sumps/pits (lined or unlined) is expressly prohibited.

12.3 Boring/Well Abandonment

12.3.1 The abandonment of any borings or wells shall be approved by the Contracting Officer or authorized representative prior to any casing removal, sealing, or backfilling. The Contractor shall provide the Contracting Officer or authorized representative with the following data:

- a. Designation of well/bore in question
- b. Current status (depth, contents of hole, stratigraphy, water level, etc)
- c. Reason for abandonment
- d. Recommendation

A written follow-up request shall be made by the contractor within five working days of the telephone request. This document shall be forwarded through EM for Contracting Officer approval and

contain the same data as above.

12.3.2 Sealing of Abandoned Wells: Once approved, the boring or well to be abandoned shall be sealed by grouting from the bottom of the boring/well to ground surface (i.e., to the maximum depth drilled/bottom of well screen) and grout pumped through this pipe until undiluted grout flows from the boring/well at ground surface. Any open or ungrouted portion of the annular space between the well casing and borehole shall be grouted in the same manner. After grout placement, the drill casing/augers may be removed. When conditions permit, the grout placement and casing removal shall be done incrementally so as to constantly maintain 10 feet of grout within the casing yet to be removed from the ground.

12.3.3 Grout Settlement: After 24 hours, the contractor shall check the abandoned site for grout settlement. That day, any settlement depression shall be filled with grout and rechecked 24 hours later. This process shall be repeated until firm grout remains at ground surface without any depressions present.

12.3.4 Well Screen and Casing Removal: Normal abandonment of monitoring wells shall include removing casing riser and well screen as well as filter pack, grout, and bentonite seal materials. This may require a partial or total hole drilling prior to sealing the well site. This determination will be made by the authorized EM representative for Contracting Officer approval when the request for well abandonment is made by the contractor. Alternate well abandonment procedures may be used with the approval of the Contracting Officer or authorized representative.

12.3.5 Well/Boring Record: For each abandoned boring/well, an entry shall be prepared in the Boring/Well Record (Data Item # A051) which includes the following information:

- a. Boring/well designation.
- b. Location with respect to the replacement boring or well (e.g., 20 feet north and 20 feet west of well 14).
- c. Open depth prior to grouting and depth to which grout pipe placed. This includes the depth of open hole, open depth to the bottom of the well, and the open depth in the well-borehole annulus.
- d. Casing left in hole by depth, composition, and size.
- e. Copy of the boring log.
- f. Diagram of abandoned well
- g. Drilled and sampled depth prior to decision to abandon site.
- h. Items left in hole by depth, description, and composition.
- i. Description and total quantity of grout used initially.
- j. Description and daily quantities of grout used to compensate for settlement.
- k. Dates of grouting.

- l. Water or mud level (specify) prior to grouting and date measured.
- m. Remaining casing above ground surface: Height above ground, size, and composition.

Note: All depths/heights shall be reported from ground surface. The original record shall be submitted to the Contracting Officer three days after abandonment is completed.

12.3.6 Replacement Borings/Wells: Replacement wells/borings shall be offset at least 20 feet from any abandoned site in a up or cross-gradient groundwater direction. Site specific conditions may necessitate variation to this placement, but any such placement shall be approved by the Contracting Officer.

12.4 Tracers, Dyes, and Other Substances

Tracers, dyes, or other substances shall not be used or otherwise introduced into borings, wells, grout, backfill, ground, or surface water unless specifically required by contract.

12.5 Geologist Requirements

A geologist representing the contractor shall be present and responsible at each operating drill rig for the logging of samples, monitoring of drilling operations, recording of water losses/gains and groundwater data, preparing the boring logs and well diagrams, and recording the well installation procedures of that rig (Data Item # A051). Each geologist shall be responsible for only one operating rig. Each geologist also shall have on-site, as a minimum, their own copy of the approved Work Plan and Safety Plan (approved after issuance of delivery order). Each geologist also shall have on-site their own 10X hand lens and weighted steel or iron tape(s) long enough to measure the deepest well within the delivery order and heavy enough to reach that depth and small enough to readily fit within the annulus between the well and drill casing. Each geologist shall also have on-site a water level measuring device (preferable electrical) and the necessary material to decontaminate the water level measuring device.

12.6 Soil Samples

12.6.1 General: Unless otherwise specified in the delivery order, intact soil samples to determine physical descriptions, retention, and physical analyses shall be taken and retained every five feet or at each major change of material, whichever occurs first, for two borings only. These samples shall be obtained with driven (e.g. split spoon), pushed (e.g. thin well), or rotary (e.g. Denison) type samplers. Auger flight or wash samples will not satisfy this requirement.

12.6.2 Soil Containers: Representative soil samples from

each sampler shall be placed in half pint or one pint glass jars with airtight, screw type lids (canning jars). These jars shall be stored in individual compartments in cardboard boxes. A single box shall not contain more than 24 one-pint jars or 48 half-pint jars. For thin wall (shelby) samples, a sample shall be retained from each tube as described above. The remaining portion may be wasted or sealed in the tube, as per testing requirement. Minimum information on each sample container shall include the boring and sample number. No geotechnical data shall appear on the container that is not specified on the boring log. Jars and tubes shall be kept from freezing.

12.7 Drilling Requirements

12.7.1 General: The contractor shall be responsible for securing and complying with any and all boring or well drilling permits required by state or local authorities and for determining and complying with any and all state and local regulations with regard to the submission of well logs, samples, etc. Submission of these items to the state or local authorities shall be coordinated through EM.

12.7.2 Safety and Utility Requirements: The contractor shall be responsible for determining and complying with any and all (to include project site) regulations, requirements, and permits with regard to drilling safety and underground utility detection. The contractor shall include a discussion of its actions with regard to these items in his Safety Plan.

12.7.3 Lubrication Requirements: Only petroleum jelly, teflon tape, lithium grease, or vegetable-based lubricants shall be used on the threads of downhole drilling equipment. Additives containing lead or copper shall not be used.

12.7.4 Surface Runoff: Surface runoff; e.g., precipitation, wasted or spilled drilling fluid, and miscellaneous spills and leaks, shall not enter any boring or well either during or after drilling/well construction. To help preclude this, the use of starter casing, recirculation tanks, berms about the borehole, and surficial bentonite packs, as appropriate, is suggested.

12.7.5 Antifreeze: If antifreeze is added to any pump, hose, etc., in an area in contact with the drilling fluid, then the antifreeze shall be completely purged from the equipment prior to the equipment's use in drilling, mud mixing, or any other part of the overall drilling operation. Only antifreeze without rust inhibitors and/or sealants shall be used. The contractor shall note on the boring log the dates, reasons, quantities, and brand names of antifreeze used.

12.7.6 Cleaning of Equipment: The steam cleaning of all

drilling equipment (to include rigs, water tanks (inside and out), augers, drill casing rods, samplers, tools, recirculation tanks, etc.) shall be done prior to project site arrival followed by washing with approved water between different boring/well sites. Prior to use on-site, all casings, augers, recirculation and water tanks, etc., shall be devoid both inside and out of any asphaltic, bituminous, or other encrusting or coating materials, grease, grout, soil, etc. Paint, applied by the equipment manufacturer, need not be removed from drilling equipment.

12.8 Drilling Methods

12.8.1 Hazardous Conditions and Soil Cuttings: The contractor shall monitor all exploratory well drilling and borehole operations with an OVA or comparable instrument to identify potential generation of hazardous and/or toxic materials. In addition, the contractor shall monitor drill cuttings for discoloration and odor. During drilling operations, if soil cuttings are suspected to be hazardous (based on OVA measurement, odors, or discoloration), the contractor shall place them in proper containers and test them using TCLP, ignitibility, or organics (EPA Method 624) as appropriate. The contractor shall handle, transport, store, treat and/or dispose of all waste, both nonhazardous and hazardous (Ref. Section 3.6). Drums shall be labeled in accordance with the Tinker AFB hazardous waste identification system (Tinker AFB Reg. 19-5). Results of this monitoring shall be included in Well/Bore Record. All cuttings on private property that are not hazardous shall be adequately collected, removed, and properly disposed.

12.8.2 Laboratory Soil Tests: Laboratory soil tests shall be taken of each formation or stratum as determined by the on-site geologist at a maximum of two bore holes or for a minimum of 20 stratums. Laboratory testing for soil samples shall as a minimum consist of moisture content and gradation analyses for 1-1/2 inch to #200 sieve; less than #200 sieve requires a hydrometer analysis, Atterberg Limits, and organic content.

12.8.3 Drilling Techniques: Wet rotary, hollow stem auger, and air rotary are acceptable drilling techniques. The technique to be used will vary with site/project requirements. Where split-spoon and shelly tube samples are required, the hollow stem auger shall be used. Samples shall be collected, containerized, described and logged at five foot intervals or at stratum changes. If saturated zones are encountered and the hole is to go through it, then advancing casing techniques shall be used by the contractor. Alternate drilling techniques may be used with the approval of the Contracting Officer or authorized representative.

12.8.4 Reserved

12.8.5 Air Compressor Oil: The contractor shall specify

the type of air compressor and lubricating oil used and retain a pint sample of each type and lot of oil for characterizations, in the event of future problems.

12.8.6 Air Line Filter: The contractor shall have a air line oil filter on the air line and shall change the filter per manufacturer's recommendation during operations with a log kept of this maintenance in the Well/Bore Record (Data Item #A051). More frequent changes shall be made if oil is visibly detected in the filtered air.

12.8.7 Additives: The use of any additives except for water and those approved by the Contracting Officer or authorized representative for dust control and cutting removal shall be prohibited. See Section 12.2.

12.8.8 Downhole Hammer/Bit: The contractor shall refrain from using any downhole hammer/bit. The contractor shall preclude residual groundwater sample contamination caused by the lubrication of the downhole equipment.

12.8.9 Air Usage: The contractor shall fully describe air usage in the Well/Bore Record (Data Item #A051) to include equipment description(s), manufacturer(s), model(s), air pressure used, frequency of oil filter change, and evaluations of the system performance, both design and actual.

12.9 Water Levels

12.9.1 Static Water Measurements: For contouring and reporting purposes (Well/Bore Record, Data Item # A051), at least one complete set of static water level measurements shall be made by the contractor over a single, consecutive 10-hour period for all wells considered in the project. Static levels in borings not converted to wells shall be included if practical and technically appropriate.

12.9.2 Other Measurements: The contractor shall determine and report the relative elevation difference to within +/- 0.5 foot, between any stream lake, or open water body, and wells located within 300 feet of these features. The contractor shall use the data for the refinement of the groundwater contours in the vicinity of the surficial water bodies and wells (Well/Bore Record, Data Item # A051).

12.9.3 Restoration of Work Area: All work areas around the well and/or boring sites installed as part of this contract shall be restored to a physical condition equivalent to that of pre-installation. This includes cutting removal and/or spreading and rut removal.

12.10 Geophysical Logs

12.10.1 Geophysical Logs: All boreholes drilled to 50 feet or deeper shall have calibrated geophysical logs run in each section of the open borehole unless otherwise authorized by the Contracting Officer or authorized representative. At a minimum, natural gamma ray, spontaneous potential, and caliper logs shall be run (Data Item #A079). The Geophysical Log shall be incorporated as part of the Well/Boring Record (Data Item #A051).

12.10.2 Submittal: Each original boring log shall be submitted directly from the field to the Contracting Officer or authorized EM representative within 3 working days after the boring is completed. In those cases where a monitoring well or other instrument is to be inserted into the boring, both the log for the boring and the installation diagram shall be submitted within 3 working days after the instrument is installed. Only the original boring log (and diagram) shall be submitted from the field to fulfill the above requirement. Carbon, typed or reproduced copies will not suffice.

12.10.3 Composing of Field Logs: The contractor shall compose logs directly in the field without transcribing from a field book or other document. This technique reduces off-site work hours for the geologist, lessens the chance for errors of manual copying, and allows the completed document to be field-reviewed closer to the time of drilling.

12.10.4 The following information shall be routinely entered on the boring log or attached to the log:

- a. Depths/heights shall be recorded in feet and fractions thereof (tenths or inches).
- b. Soil classifications shall be in accordance with the Unified Soil Classification System (equivalent to ASTM D 2487-85).
- c. Soil classifications shall be prepared in the field at the time of sampling by the geologist and are subject to change based upon laboratory tests and/or subsequent review. Any such changes shall be incorporated in the project report(s). The reports and boring logs shall be corrected by the contractor. A separate addendum to the logs for these changes shall be included with the geotechnical or final report submission, as appropriate.

12.10.5 Soil Sample Descriptions: Each soil sample taken shall be fully described in the log. The descriptions of intact samples shall include the following parameters:

<u>Parameter</u>	<u>Example</u>
Classification	Sandy Clay

Unified Soil Classification Symbol

CL

Secondary Components & Estimated Percentages Sand: 25% (Fine sand 5% Coarse sand, 20 %)

Color (using Munsell Coil or Geological Society of America ((GSA) Rock Color Chart), give both narrative and numerical description. Munsell and note which chart used. Gray: 7.5 YR 5/0 Munsell

Plasticity Low Plasticity

Consistency (cohesive soil) Stiff

Density (non-cohesive soil) Loose

Moisture Content, do not express as a percentage unless a lab value Dry, moist, wet, etc.

Texture/Fabric/Bedding & Orientation No apparent bedding; numerous vertical, iron-stained tight fractures

Depositional Environment & Formation, Glacial till, Twin Cities Formation

12.10.6 Secondary Soil Constituents: In the field, visual numeric estimates shall be made of secondary soil constituents; e.g. "silty sand with 20 percent fines" or "sandy gravel with 40 percent sand". If such terms as "trace", some, several, etc., are used, their quantitative meaning is to be defined on each log or within a general legend.

12.10.7 Disturbed Samples: When used to supplement other sampling techniques, disturbed samples; e.g., wash samples, cutting, and auger flight samples shall be described in terms of the appropriate soil/rock parameters to the extend practical. "Classification" shall be minimally described for these samples, along with a description of drill action and water losses/gains for the corresponding depth.

12.10.8 Bentonite Use: The contractor shall record the brand name and amount of any bentonite used for each boring along with the reason for its use and the starting depth.

12.10.9 Drilling Equipment: The drilling equipment used shall be generally described on the log or in a general legend in the Well/Bore Record (Data Item # A051). Record such information as rod size, bit type, pump type, rig manufacturer and model. The log shall record the drilling sequence; e.g.:

- a. Opened hole with 8" auger to 9'.
- b. Set 8" casing to 10'.
- c. Cleaned out and advanced hole with 8" roller bit to 15' (clean water, no water loss).
- d. Drove standard sampler to 16.5'.
- e. Advanced with 8" roller bit to 30', 15 gallon water 1055.
- f. Drove standard sampler to 31.5'.
- g. Hole heaved to 20'.
- h. Mixed 25 pounds of ABC bentonite in 100 gallons of water for hole stabilization and advanced with 8" roller bit to 45', etc.
- i. The contractor shall record all special problems and their resolution on the log; e.g., hole squeezing, recurring problems at a particular depth, grout in wells, excessive grout takes, drilling fluid losses, unrecovered tools in hole, lost casings and screens, etc.
- j. The dates for the start and completion of borings shall be recorded by the contractor on the log along with notation by depth for drill crew shifts and individual days.
- k. Each sequential boundary between the various soils and individual technologies shall be noted by the contractor on the log by depth. When depths are estimated, the estimated range shall be noted along with the boundary.
- l. The depth of the first encountered free water shall be indicated along with the method of determination; e.g., "37.6' from direct measurement after drilling to 40.0 feet"; or "40.1' from the direct measurement in 60' hole when boring left overnight, hole dry at end of previous shift;; or "25.0' encountered water to partially stabilize (5 to 10 minutes) and record this secondary level and time between measurements before proceeding. Also, describe any other distinct water level(s) found below the first.
- m. The estimated interval by depth for each sample taken, classified, and/or retained shall be noted on the log. For each driven (split spoon), thin wall (shelby), and cored sample, record the length of sampled interval and length of sample recovery. Record the sampler type and size (diameter and length).
- n. Record the blow counts, hammer weight, and length of hammer fall for driven samplers. For thin wall samplers, indicate whether the sampler was pushed or

- driven.
- o. When drilling fluid is used, quantitatively record fluid losses and/or spillage and intentional wasting (e.g., recirculation tank cleaning) to more accurately estimate the amount of fluid lost to the subsurface environment.
- p. Record the pumping pressures typically used during oil rotary drilling operations.
- q. Note the total depth of drilling sampling, whichever is deeper, on the log.

12.11 Well Installation

12.11.1 Beginning Well Installation: The installation of each type of well shall begin within 12 consecutive hours of boring completion for uncased or partially cased holes. Installation shall begin within 48 consecutive hours for fully cased holes. Once installation has begun, no breaks in the installation process shall be made until the well has been grouted and drill casing removed. Exceptions shall be requested in writing by the contractor through EM for Contracting Officer approval prior to drilling. Data to include in this request are:

- a. Well(s) in question.
- b. Circumstances.
- c. Recommendation and alternatives.

Note: Allow three working days from the time of receipt by EM for Contracting Officer approval.

12.11.2 Delays: In cases of unscheduled delays such as personal injury, equipment breakdowns, sudden inclement weather, or scheduled delays such as borehole geophysics, no advance approval of delayed well installation is needed. In those cases, installation shall be resumed as soon as practical. In cases where a partially cased hole into bedrock is to be somewhat developed prior to well insertion, the well installation shall begin within 12 consecutive hours after this initial development.

12.11.3 Interruptions: Once begun, well installation shall not be interrupted due to the end of the contractor's/driller's work shift, darkness, weekend, or holiday. The contractor shall ensure that all materials for a given well are available and on-site prior to drilling that well.

12.12 Granular Backfill

12.12.1 Approval of Backfill: The contractor shall determine the granular backfill and screen slot size. All granular backfill shall be approved by the Contracting Officer prior to drilling. A one-pint representative sample of each proposed granular backfill (sand/gravel or filter pack) accompanied by the data below is required for Contracting Officer approval prior to

drilling. Each sample shall be described, in writing, in terms of:

- a. Lithology.
- b. Grain size distribution.
- c. Trade name, if any.
- d. Source, both company from whom purchased and location of pit or quarry of origin.
- e. Processing method; e.g., pit run, screened and unwashed, screened and washed with water from well/river/pond, etc.
- f. Slot size of intended screen.

Allow eight working hours for Contracting Officer's approval once all of the above data is received by EM.

12.12.2 Backfill Characteristics: Granular backfill shall be chemically and texturally clean (as seen through a 10X hand lens), inert, siliceous, and of appropriate size for the well screen and host environment.

12.12.3 Backfill level: Granular backfill (sandpack/filter pack) shall extend a maximum of 2 feet above the screen unless otherwise specified in the Statement of Work. In wells constructed deeper than 200 feet, up to 5 feet of sandpack may be required to account for possible compression of the filterpack material. The filterpack shall not penetrate any confining layer either above or below the screen interval without the approval of the Contracting Officer or authorized representative.

12.13 Protective Casing

12.13.1 General: The contractor shall install the protective casing around each monitoring well within 24 hours of initial grout placement around that well unless flush mounted. Requests for exceptions on usage, design, and timing of placement will be considered on a case-by-case basis by the Contracting Officer. Requests in writing shall be made through the authorized EM representative prior to drilling. Include in the request the well(s) involved, reason for request, cost savings, recommendation, and alternatives. Allow six working days for Contracting Officer's approval after the request is received by EM.

12.13.2 The contractor shall include the minimum elements of protection design listed below:

- a. A black iron/steel protective casing with hinged locking cover unless wells are flush mounted. The protective casing shall be a minimum length of 5 feet, extending about 2.5 feet above ground surface with the base set in grout.
- b. A 8" protector pipe for 5" wells.

- c. A 6" protector pipe for 4" wells.
- d. A 5" protector pipe for 3" wells.
- e. A 4" protector pipe for 2" wells.
- f. A highted cover or loose fitting telescoping cap to keep precipitation and runoff out of the casing.
- g. All protective casing covers/caps secured to the casing by means of a padlock from the date of protective casing installation.
- h. All padlocks to be placed on monitoring wells shall match locks on existing wells and be keyed the same.
- i. No more than 3.6" from the top of protective casing to the top of well casing.
- j. All above ground well completions shall be painted black with a white cover. White well numbers shall be painted on the black exterior of the protective casing in large enough letters/numbers to be identified from a distance of 50 feet. Painting shall be accomplished with a paint brush (no aerosol cans), and must be dry prior to development.
- k. The well designation shall be permanently stamped on the top of the hinged locking cover and on top of each well cap for the above ground well completions. For flush mount completions, the well designation shall be stamped on the bolt down cover and on the top of the well cap.
- l. The four-foot radial placement of four guard posts: Each post shall be 6" diameter steel and placed about three feet below ground, rising three feet minimally above ground. Guard posts shall be painted yellow. Installation required prior to sampling.
- m. The placement of an internal mortar collar within the well-protective casing annulus from ground surface to 1/2-foot above ground surface with a 1/4" diameter hole (drainage port) in the protective casing centered 1/8" above this level. The mortar mix shall be (by weight) one part cement to two parts sand (the granular backfill used about the well screen), with minimal water for placement. Placement required at least 48 consecutive hours prior to well development.
- n. The application of an 8 inch thick, 3-foot by 3 feet concrete pad sloped away from the monitoring well casing to prevent water from collecting around and entering into the well. The pads shall be contoured so that the edge of the pad is flush with the surrounding surface elevation. Completion of the pad is required prior to development.
- o. Unique specifications for flood protection, if applicable, are covered in the Statement of Work.
- p. Flush surface completions shall have bolt down covers with water proof seals and a

locking mechanism on the well cap.

12.14 Grout and Placement

12.14.1 General: Grout, when used in monitoring well construction or well abandonment, shall be composed by weight of 10 parts cement (portland cement, any of types I to V) to 1/2 part bentonite with a maximum of 10 gallons of approved water per 94-pound bag of cement. Neither additives nor borehole cuttings shall be mixed with the grout. Bentonite shall be added after the required amount of cement is mixed with water. All grout materials shall be combined in an above-ground rigid container and mixed on-site to produce a thick, lump-free mixture.

12.14.2 Grouting Monitoring Wells (bentonite seal): Grout shall be placed in the monitoring wells as follows when a bentonite seal is used:

- a. Prior to exposing any portion of the borehole above the seal by the removal of any drill casing (to include hollow-stem augers), the annulus between the well casing shall be filled with grout.
- b. The grout shall be placed from within a tremie pipe, located just over the top of the seal.
- c. The grout shall be pumped through this pipe to the bottom of the open annulus until undiluted grout flows from the annulus at ground surface, forming a continuous grout column from the seal to ground surface.
- d. The drill casing shall then be removed and more grout immediately added to compensate for settlement.
- e. If drill casing (to include hollow-stem auger) was not used, the contractor shall proceed with grouting to ground surface in one, continuous operation.
- f. After 24 hours, the contractor shall check the site for grout settlement and that day add more grout to fill any settlement depression.
- g. The process shall be repeated until firm grout remains at ground surface.
- h. Incremental quantities of grout added in this manner shall be recorded as added to the Well/Bore Record.

12.14.3 RESERVED

12.15 Bentonite Seals

12.15.1 General: Bentonite seals shall be composed of commercially available pellets. Pellet seals shall be a minimum of five feet thick as measured immediately after placement, without allowance for swelling.

12.15.2 Slurry Seals: The contractor shall only use slurry

seals as a last resort, as when the seal location is too far below water to allow for pellet or containerized-bentonite placement within a narrow well-borehole annulus. Slurry seals shall have a thick, batter-like consistency with a placement thickness of five feet maximum.

12.15.3 Bedrock: In wells designed to monitor bedrock, the bentonite seal shall be located at least three feet below the top of firm bedrock, as may be determined by drilling refusal. Firm bedrock references to that portion of solid or relatively solid, moderately to unweathered bedrock where the frequency of loose and fractured rock is markedly less than in the bentonite seal and the top of the highly weathered bedrock shall be filled with grout.

12.15.4 Purging Borehole: When a borehole, made with or without the use of drilling fluid, retains an excessively thick, particulate laden fluid which would preclude or practically hinder contractual well installation, the bore may be purged with approved water. This purging is intended to remove or dilute the thick fluid and thus allow the proper placement of well, granular backfill and seal. Fluid losses in this operation shall be initially recorded on the well diagram or Well/Boring Record.

12.15.5 Well Centralizers: Well centralizers, when used, shall be of stainless steel or polyvinyl chloride (PVC) and shall be attached to the riser with stainless steel clamps. No glue of any kind shall be used. Centralizers shall not be attached to the well screen or to that part of the well casing exposed to the granular backfill.

12.15.6 Caps: The tops of all well casings shall be fitted with undersized PVC plugs or oversized PVC caps both of which shall be easily removed by hand.

12.16 Well Screens, Casings, and Fittings

12.16.1 Materials: PVC, fiberglass, and/or stainless steel shall be used for well casings and fittings.

12.16.2 Well Screens: All well screens shall be stainless steel, commercially fabricated, slotted or continuously wound, and have an inside diameter equal to or greater than the well casing. Stainless steel screens may be used with PVC casing. No fitting (coupling) shall restrict the inside diameter of the joined casing and/or screen. All screens, casings and fittings shall be new. Schedule 40 PVC pipe shall be used for shallow upper zone wells and schedule 80 PVC pipe for deeper wells (over 100 feet).

12.16.3 Foreign Matter: The contractor shall ensure that all well screens and well casings are free of foreign matter (e.g., adhesive tape, labels, soil, grease, etc) and washed with approved water prior to use. Washed screens and casings shall be stored in

plastic sheeting or kept on racks prior to insertion. The contractor shall run a dummy pump through all screen and casing to ensure access by pumps and bailers.

12.16.4 Screen Placement: The contractor shall place well screens no more than three feet above the bottom of the drilled bore hole; holes that are deeper than screen location shall be backfilled with bentonite slurry.

12.16.5 Caps: All screen bottoms shall be securely fitted with a cap or plug of the same composition as the screen. This cap/plug shall be within 0.5 foot of the open portion of the screen.

12.16.6 Silt Traps: Installation of a silt trap (sump) may be necessary and depends on site/project requirements. Sumps shall extend a maximum of 3 feet below the bottom of the screen and shall not penetrate the lower confining layer.

12.16.7 Joints: Joints within and between the casing and screen shall be threaded with matching threads. All joints shall be flush inside. Non-factory, heat-welded joints shall not be used. The addition of "O" ring seals will depend on site specific requirements and shall be approved by the Contracting Officer or designated representative.

12.17 Well Construction Diagrams

12.17.1 General: Each installed well shall be depicted in a well diagram prepared by the contractor. This diagram shall be attached to the bore log for that installation and shall graphically denote, by depth from ground surface (unless otherwise specified), the following:

I. General:

- a. The bottom of the boring (that part of the boring most deeply penetrated by drilling and/or sampling).
- b. Screen location(s).
- c. Granular backfill.
- d. Seals.
- e. Grout.
- f. Cave-in.
- g. Centralizers.
- h. Height of riser without cap/plug (above ground surface).

II. Protective Casing Details:

- a. Height of protective casing without cap/cover (above ground surface).
- b. Base of protective casing.

- c. Drainage port location and size.
- d. Internal mortar collar location.
- e. Gravel blanket height and extent.
- f. Wood/steel post configuration.

III. Describe on the diagram or on an attachment thereto:

- a. The actual quantity and composition of the grout, seals, and granular backfill used for each well.
- b. The screen slot size (in inches), slot configuration, total open area per foot of screen, outside diameter, nominal inside diameter, schedule/thickness, composition, and manufacturer.
- c. The coupling/joint design and composition.
- d. Centralizer design and composition.
- e. Protective casing composition and nominal inside diameter.
- f. The use of solvents, glues, and cleaners to include manufacturer and type (specification).
- g. Dates for the start and completion of well installation.

12.17.2 Submittal: The contractor shall submit each diagram (attached to the boring log) to the authorized EM representative within three working days after well installation. Do not delay this submission until all elements of well protection have been installed. The contractor shall submit a supplemental diagram for all protection elements to the authorized EM representative within three working days after all elements of well protection are installed. Only the original well diagram and log shall be submitted to fulfill the above requirement. Carbon, typed, or reproduced copies shall not suffice. A legible copy of the well diagram may be used as a base for the supplemental protection diagram.

12.18 Well Development

12.18.1 General: After installation, wells shall be properly developed by the contractor. Development methods for all wells shall be approved by the Contracting Officer or authorized representative. Natural hydraulic conductivity of the formation shall be restored and all foreign sediment removed by the contractor to ensure turbid-free groundwater samples. The contractor shall provide references that affirm his development procedures. Correct development procedures can expedite sample filtration and can have affect on samples being representative of water in the formation being monitored. Development shall be accomplished with a pump and may be supplemented with a bottom discharge/filling bailer (for sediment removal). A bottom discharge/filling bailer may be used in lieu of a pump in 2-inch wells.

12.18.2 Schedule: The development of monitoring wells shall be performed as soon as practical after well installation, but no sooner than 48 consecutive hours after internal mortar collar placement. The record of well development shall be submitted to the Contracting Officer within three working days after development.

12.18.3 Development shall proceed in the manner described and continue until the following conditions are met:

- a. The well water is clear to the unaided eye.
- b. The sediment thickness remaining within the well is less than 5% of the screen length.
- c. In addition to minimally removing 5 times the standing water volume in the well (to include the well screen and casing plus saturated annulus, assuming 30% porosity), the following conditions also apply:

1. For those wells where the boring was made by the use of cable tool, auger, or air rotary methods and without the use of drilling fluid (mud and/or water), only the five volumes need to be minimally removed. Should recharge be so slow that the required volume cannot be removed in 48 consecutive hours, or the water remains discolored or excess sediment remains after the five volume removal, the authorized EM representative shall be contacted for guidance.

2. For those wells where the boring was made or enlarged (totally or partially) with the use of drilling fluid (mud and/or water), the contractor shall remove 5 times the measured amount of total fluids lost while drilling plus 5 times the standing water volume as above. The same procedure applies here as above with respect to slow recharge, discoloration, and sediment thickness.

3. In some instances, water may be added to a well as part of development once the initial seal is placed. Addition of water will depend on site/well requirements. The type and amount of water added shall have prior approval of the Contracting Officer or designated representative. When a bore, made with or without the use of drilling fluid, contains an excessively thick, particulate-laden fluid which would preclude or practically hinder well installation, the contractor may purge or dilute this fluid with clean water from the approved source. A record of purging fluid losses shall be made on the Well/Boring Record (Data Item # A051).

4. No dispersing agents, acids, disinfectants, or other additives shall be used during development or at any other time introduced to the well.

5. Well development shall be completed by the contractor at least 3 consecutive days before well sampling.

6. During development, water shall be removed throughout the entire water column by periodically lowering and raising the pump intake (or bailer stopping point).

7. For each well, a one-pint sample of the last water to be removed during development shall be obtained and kept on-site for visual inspection in an area where they will not freeze.

8. Contaminated water from bore holes and monitoring wells shall be containerized for proper disposal per the installation requirements.

9. Part of well development shall be the washing of the entire well cap and the interior of the well casing above the water table using only water from that well. The result of this operation shall be a well casing free from extraneous materials (grout, bentonite, sand, etc) inside the riser, well cap, and block casing between the top of the well casing and the water table. This washing shall be conducted before and/or during development, not after development.

12.18.5 The following data shall be recorded as part of development in the Well/Borehole Record (Data Item A051):

- a. Well designation.
- b. Date(s) of well installation.
- c. Date(s) and time of well development.
- d. Static water level from top of well casing before and 24 consecutive hours after development.
- e. Quantity of mud/water lost:
 - i) During drilling.
 - ii) During fluid purging.
- f. Quantity of fluid in well prior to development:
 - i) Standing in well.
 - ii) Contained in saturated annulus (assume 30% porosity).
- g. Field measurement of pH before, twice during, and after development using an electrometric device (EPA 150.1 Methods for Chemical Analysis of Water and Wastes, EPA 600/479-020).
- h. Field measurement of specific conductance before, twice during, and after development using conductivity meter (EPA 120.1 - Methods for Chemical Analysis of Water and Wastes, EPA 600/4 - 79-020). Obtain conductance and pH readings concurrently.
- i. Depth from top of well casing to bottom of well (from diagram).
- j. Screen length (from diagram).
- k. Depth from top of well casing to top of sediment inside well, before and after development.
- l. Physical characteristic of removed water, to include changes during development in clarity, color,

- particulates, and odor.
- m. Type and size/capacity of pump and/or bailer used.
- n. Description of surge technique, if used.
- o. Height of well casing above ground surface.
- p. Quantity of fluid/water removed and time for removal (present both incremental and total values).
- q. Name and phone number of approving State or Federal EPA representative.

12.18.6 Water removed from the well for development shall not be counted toward the volumetric removal requirements of any pre-sample purging.

12.19 Well Acceptance Criteria

12.19.1 General: Wells shall be approved by the Contracting Officer. Well approval shall be on a case-by-case basis. The following criteria shall be used in the evaluation process. Wells not meeting these criteria are subject to rejection.

- a. The well and backfill shall meet the construction specifications in this SOW and the placement specifications listed in the Delivery Order.
- b. Wells/bore holes shall not contain uncovered portions of drill casing or augers.
- c. All well casing and screen materials shall be free of any unsecured couplings, ruptures or other physical breakage/defects before and after installation.
- d. The annular material surrounding each installed well shall form a continuous and uniform structure, free of any fractures or cracks.
- e. Any casing or screen deformation or bending shall be minimal to the point of allowing the insertion and retrieval of the pump and/or bailer optimally designed for that size casing (e.g., a 4-inch pump in a 4-inch schedule 40, PVC casing is optimal; a 2-inch in a 4-inch casing is not optimal).
- f. All joints shall be constructed to provide a straight, non-contracting, and water-tight fit.
- g. Well backfill materials (e.g., filter pack, bentonite, and grout) shall form a continuous annular filling around the well casing.
- h. Installed wells shall be free of foreign objects/materials (tools, pumps, bailers, soils, grout, etc.).
- i. At least 75 % of the well screen shall be below water at the time of measurement for those screen depths determined by the contractor.

12.20 Topographic Survey

- 12.20.1 Horizontal Control: Each boring and/or well

installed under this contract shall be topographically surveyed by a licensed surveyor to determine its map coordinates to within $\pm .5$ ft (± 15 centimeters) using a State Plane Lambert Coordinate System. Coordinates shall be reported in meters or feet using the 1983 North American Datum, Oklahoma North Zone; and in feet using the 1927 North American Datum, Oklahoma North Zone. The Contracting Officer or designated representative will provide a list of permanent monuments acceptable for establishing horizontal and vertical control.

12.20.2 Vertical Control: Elevations for the ground surface (not the top of the coarse gravel blanket) and the top of the well casing (not protective casing) for each bore/well site shall be surveyed by a licensed surveyor to within ± 0.01 foot (± 3 millimeters) using the National Geodetic Vertical Datum of 1929.

12.20.3 Survey Field Data: Survey field data (as corrected), to include loop closure for survey accuracy, shall be submitted through EM to the Contracting Officer with the required submission. Closure shall be within the horizontal and vertical limits given above. This submission shall clearly list the coordinates (and system) and elevation (ground surface and/or top of well casing, as appropriate) for all borings, wells, and reference marks. All permanent and semipermanent reference marks used for horizontal and vertical control (bench marks, caps, plates, chiseled cuts, rail spikes, etc.) shall be described in terms of their name, character, and physical location.